(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 627 029 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
05.01.2000 Bulletin 2000/01

(21) Application number: **92914663.7**

(22) Date of filing: **24.04.1992**

(51) Int Cl.[7]: **D21C 7/00**, D21C 9/153, D21C 9/10

(86) International application number:
PCT/US92/03389

(87) International publication number:
WO 93/14260 (22.07.1993 Gazette 1993/18)

(54) PULP BLEACHING APPARATUS AND METHOD

VORRICHTUNG UND VERFAHREN ZUM BLEICHEN VON ZELLSTOFF

APPAREIL ET METHODE POUR LE BLANCHIMENT D'UNE PATE

(84) Designated Contracting States:
AT BE CH DE DK ES FR GB GR IT LI LU MC NL SE

(30) Priority: **15.01.1992 US 821117**

(43) Date of publication of application:
07.12.1994 Bulletin 1994/49

(73) Proprietor: **UNION CAMP PATENT HOLDING, INC.**
Wilmington, DE 19801 (US)

(72) Inventors:
- **WHITE, David C.**
  Pennington, NJ 08534 (US)
- **PIKULIN, Michael**
  Bound Brook, NJ 08805 (US)
- **GANDEK, Thomas P.**
  Trenton, NJ 08618 (US)
- **FRIEND, William H.**
  Savannah, GA 31411 (US)

(74) Representative: **Larsen, Hans Ole et al**
Larsen & Birkeholm A/S,
Banegaardspladsen 1,
P.O. Box 362
1570 Copenhagen V (DK)

(56) References cited:
EP-A- 0 308 314
EP-A- 0 492 040
EP-A- 0 515 303
WO-A-91/18145
WO-A-92/07999
WO-A-92/12289
US-A- 1 781 712
US-A- 4 248 662
US-A- 4 278 496
US-A- 4 363 697

EP 0 627 029 B1

Description

Field of the Invention

[0001] The present invention relates to a pulp bleaching apparatus as stated in the introdoctory part of claim 1 and method for bleaching lignocellulosic pulp with ozone as stated in the introdoctory part of claim 19, and more particularly, a reactor including rotating elements to convey radially dispersed pulp particles through an ozone containing gas in a plug flow-like manner.

Background of the Invention

[0002] To avoid the use of chlorine as a bleaching agent for pulp or other lignocellulosic materials, the use of ozone in the bleaching of chemical pulp has previously been attempted. Although ozone may initially appear to be an ideal material for bleaching lignocellulosic materials, the exceptional oxidative properties of ozone and its relatively high cost have previously limited the development of satisfactory ozone bleaching processes for lignocellulosic pulps.

[0003] Numerous articles and patents have been published related to ozone bleaching of pulp. For example, bleach sequences using ozone are described by S. Rothenberg, D. Robinson and D. Johnsonbaugh, "Bleaching of Oxygen Pulps with Ozone", Tappi, 182-185 (1975) - Z, ZEZ, ZP and ZP_a (P_a-peroxyacetic acid); and N. Soteland, "Bleaching of Chemical Pulps with Oxygen and Ozone", Pulp and Paper Magazine of Canada, T153-58 (1974) - OZEP, OP and ZP. Further, US-A-4,196,043 to Singh discloses a multi-stage bleaching process utilizing ozone and peroxide with effluent recycle, which also attempts to eliminate the use of chlorine compounds.

[0004] Also, various patents disclose vertical bed type reactors for ozone bleaching of pulp in a high consistency range, wherein the pulp is deposited at the top of an essentially quiescent or slowly moving bed and an ozone containing gas is drawn through the bed. For example, Fritzvold US-A- 4,278,496 discloses a vertical ozonizer for treating high consistency (i.e., 35-50%) pulp. Both oxygen/ozone gas and the pulp are conveyed into the top of the reactor to be distributed across the entire cross-section, such that the gas comes in intimate contact with the pulp particles. The pulp and gas mixture is distributed in layers on supporting means in a series of subjacent chambers. The supporting means includes apertures or slits having a shape such that the pulp forms mass bridges thereacross, which the gas passes throughout the entire reactor in contact with the pulp.

[0005] Fritzvold et al. US-A-4,123,317 more specifically discloses the reactor described in the aforementioned Fritzvold '496 patent and Fritzvold et al. US-A-4,279,694 discloses a method and system for ozone bleaching of pulp using a reactor apparatus as described in the '496 patent. US-A-3,785,577, 3,814,664 and 3,964,962 to Carlsmith each disclose reactor apparatus employing a vertical design similar to the Fritzvold devices, with the '664 patent directed specifically to ozone bleaching. The vertical bed type design described in the preceding patents provides unsatisfactory results with regard to bleaching uniformity.

[0006] The ozone reactor disclosed in EP-A-0 308,314 utilizes a closed flight screw conveyor (an "Archimedes screw") wherein the ozone is pumped through a central shaft and injected into the reactor to treat a layer of pulp that is ideally about 10 cm in height. The pulp has a consistency of 20-50%. EP-A-0 276,608 discloses a further device for ozone treatment of pulp. In this device a double screw machine, with sections of reverse threads, sequentially compresses and expands the pulp, preferably at 40 to 45% consistency, to provide access of the ozone to the pulp fibers.

[0007] Ozone readily reacts with lignin to effectively reduce the amount of lignin in the pulp. But it will also, under many conditions, quickly remove excessive amounts of lignin and aggressively attack the carbohydrate which comprises the cellulosic fibers of the wood to substantially reduce the strength of the resultant pulp. For these reasons, and notwithstanding the various disclosures discussed above, the art generally teaches away from ozone bleaching of pulp at high consistency. For example, Lindholm, "Effect of Heterogeneity in Pulp Bleaching with Ozone", Papieri ja Puu, p.283, 1986, states that the ozone pulp reaction may be "quite heterogeneous" (non-uniform) at pulp consistencies in the range of 30-40%. The heterogeneity is said to be due to part of the pulp receiving greater than average ozone doses while other portions of the pulp do not react at all with the ozone. Also, a recently published CA-A-2,012,771 (published November 10, 1990) discloses a method of bleaching medium consistency pulp with ozone by creating a foam-like mixture of ozone, water and pulp. This application teaches that bleaching at 30% consistency yields worse results than at 10% or 1% consistency due to outer pulp surfaces being overbleached and inside surfaces being unbleached.

[0008] A further type of reactor is disclosed in US-A-4,363,697 to Markham et al. for oxygen delignification of pulp at medium consistency. The Markham device may include a series of screw flights or modified screw flights, with and without paddles, to convey the pulp through a reaction tube in the presence of oxygen. US-A-4,384,920 to Markham et al. also discloses the use of paddle flights rotated at low speed to convey pulp through the presence of an oxygen gas flow. However, the method disclosed in the Markham patents is generally unsuitable for ozone bleaching reactions due to the much faster reaction rate of ozone and pulp/lignin as compared to that of oxygen and pulp/lignin, and also

due to the inability of the device disclosed by Markham to provide uniform gas-fiber contacting and uniform bleaching.

[0009] The heterogeneity or non-uniformity problem discussed above may be at least partially overcome by bleaching at medium to low consistency. At medium to low consistency the increased water content allows the ozone to diffuse more evenly through the pulp to increase uniformity. However, the increased water content creates other disadvantages which may outweigh the increased uniformity. The primary disadvantage arises from the increased time required for diffusion of the ozone when there is more water present. This leads to increased ozone decomposition in the water and therefore higher ozone expense as well as poorer bleaching selectivity because of the effects of the ozone decomposition by-products. The result is that at medium to low consistency greater amounts of ozone are required to achieve results equivalent to high consistency bleaching. However, as understood by persons skilled in the art, there is a practical limit on the amount of ozone that can be dissolved in water due to ozone solubility in water. Therefore, it is often not practical or cost effective to attempt to achieve significant increases in brightness with ozone at medium to low consistency.

[0010] Another area related to the present invention is the art of conveying, and in particular, with paddle conveyors. The dimensions of flat paddles for use in various diameter paddle conveyors have been standarized by the Conveyor Equipment Manufacturer's Association ("CEMA") in their bulletin ANSI/CEMA 300-1981, entitled "Screw Conveyor Dimensional Standards". Also, Colijn, "Mechanical Conveyors for Bulk Solids", Elsevier, New York, 1985, may be referred to as general background in conveying. Although typical prior art conveyors are useful for exposing material to reactive environments or for general blending of bulk solids, and a number of references discussed above use various types of conveyors, prior art conveyors in general are not capable of providing the necessary dispersion of pulp into an ozone containing gas in order to achieve an efficient and uniform ozone bleaching reaction and avoid the problems of the prior art discussed above.

[0011] Moreover, the previously mentioned US-A-4,363,697 (Markham) teaches that the conveying rate in each of the reactors in the oxygen delignification apparatus can be varied by varying the rotational speed of the screw.

[0012] Further, WO-A-91/18145, which is the earlier work of the present applicant, teaches a process for the manufacture of a substantially uniform bleached pulp, comprising turbulently mixing the pulp with an ozone containing gaseous mixture in a dynamic reaction zone for a time and at a temperature sufficient to allow access of the ozone to substantially all of the pulp for reaction, while the pulp is conveyed through the reaction zone.

Summary of the Invention

[0013] It is therefore an object of the present invention to provide a reactor apparatus and a method for effectively bleaching cellulosic pulp at high consistency using ozone to obtain a substantially uniformly increased brightness pulp.

[0014] It is a further and more specific object of the invention to maximize exposure of the pulp particles to the ozone while at the same time ensuring that every particle is exposed to ozone for approximately the same amount of time by arranging the bleaching apparatus according to the invention as stated in the characterizing part of claim 1.

[0015] In this regard the present invention provides a unique structure capable of maximizing radial dispersion of pulp particles into an ozone containing gas phase while at the same time conveying the particles through the gas phase with minimum axial dispersion. This feature ensures that a majority of the pulp particles are suspended in the gas phase and exposed to the ozone each for approximately the same time, because the entering pulp, with the lowest bulk density, is conveyed the fastest, and the conveying rate decreases as the bulk density increases due to compaction forces.

[0016] The overall bleaching apparatus according to the invention generally comprises fluffer means, reactor apparatus for bleaching high consistency pulp, pulp de-entrainment means, reaction quenching means and means for receiving and discharging bleached low consistency pulp.

[0017] The fluffer means reduces floc size of the pulp and provides the pulp with a decreased bulk density.

[0018] The reactor apparatus includes an elongated shell adapted to receive the pulp and the ozone containing gas. Ozone containing gas inlets are provided in a variety of configurations to provide means for introducing a gas flow into the bleaching apparatus and reactor shell. The shell defines a pulp inlet, which receives the pulp from the fluffer, and a pulp outlet. Preferably the shell is cylindrical and approximately horizontal. The reactor apparatus further includes means for conveying the high consistency pulp in a plug flow-like manner through the shell with the pulp radially dispersed across the entire cross-section of the shell such that a majority of pulp particles are suspended in the ozone containing gas to provide a radially dispersed and plug flow-like movement of pulp through the shell.

[0019] The rotating means comprises first means for conveying the pulp introduced through the inlet and having a first bulk density at a first conveying rate and second means for gradually reducing the conveying rate through the shell to a second lower conveying rate which conveys the radially disposed pulp particles through the shell to the outlet, whereby the density of the pulp is gradually increased by the second means to a second increased bulk density. The pulp entering the inlet is received by the first conveying means at the decreased bulk density provided by the fluffer. The first conveying means acts on the pulp to increase the bulk density and delivers the pulp to the second conveying

means at an increased bulk density.

[0020] According to a preferred embodiment of the invention, the rotation means comprises a conveyor having a first section that provides the initial and reducing conveying rates and a second section that provides the second conveying rate with a dispersion index for the pulp of less than about 7. More specifically, at least the second section of the conveyor comprises radially extending members mounted in a predetermined arrangement on a rotatable shaft, and the dispersion index is maintained at all rotational speeds of said rotating means under about 125 rpm. Further, the members in the second section are arranged around the shaft at 120° or 240° spacings in a helical quarter- or half-pitch pattern.

[0021] It is also preferred that said radially extending members define a rotational diameter for the conveyor and said members are paddles located in both the first and second sections of the conveyor with a preselected number of the paddles having a width of less than about 0.3 times the rotational diameter. More specifically, a first portion of the preselected number of paddles each has a width equal to about 0.15 times the rotational diameter and a second portion of said number each has a width greater than the paddles of the first portion, and wherein the paddles of the first portion provide a conveying rate which is less than that of the paddles of the second portion at the same rotational speed, with the first portion of paddles located in the second conveyor section and the second portion of the paddles located in the first conveyor section.

[0022] Further details about the first and second conveying means are stated in claims 7-16.

[0023] The bleaching apparatus according to claim 17 further comprises a receiving tank and means for quenching the ozone reaction.

[0024] The quenching means quenches (stops) the ozone bleaching reaction on the pulp by adding water to the pulp. The quenching means is located to receive pulp from the reactor apparatus outlet. Adding water to the pulp also lowers its consistency. The means for receiving the lowered consistency pulp from the quenching means is preferably a tank with an agitating device.

[0025] Instead of paddle blades or screw flights, a series of wedge-shaped flights or elbow shaped lifters can be used, provided that they are spaced at a sufficient distance to minimize or avoid bridging or plugging of the pulp particles therebetween.

[0026] Finally, the ozone containing gas in the reactor apparatus is adapted to flow cocurrently to the movement of pulp and is supplied into the reactor shell through multiple ports therein.

[0027] According to the method of the present invention as described in claim 19, the bleaching process comprises initially conveying the pulp particles at a first conveying rate followed by gradually reducing the conveying rate of the pulp to a second lower conveying rate; while dispersing and conveying the pulp particles substantially completely throughout the reaction zone in a plug flow-like manner at the second conveying rate, whereby the pulp density is increased from a first bulk density at the first conveying rate to a second increased bulk density at the second conveying rate.

[0028] Further details of the method for ozone bleaching are stated in claims 20-25.

Brief Description of the Drawings

[0029]

FIG. 1 is a side elevation view of the apparatus according to the present invention with a portion cut away to show the paddle conveyor;

FIG. 2 is an enlarged side elevation view of the quenching zone of the apparatus shown in FIG. 1;

FIG. 3 is a side view of an alternative embodiment of the present invention illustrating multiple port gas inlets;

FIG. 4 is a cross-sectional view of the apparatus shown in FIG. 3;

FIG. 5 is a partial side view of the paddle conveyor of the upper section of the reactor apparatus illustrated in FIG. 1;

FIG. 6 is a partial side view of the paddle conveyor of the lower section of the reactor apparatus illustrated in FIG. 1;

FIG. 7 is a sectional end view of the paddle conveyor shown in FIG. 5 as viewed along line 7-7;

FIG. 8 is a sectional end view of the paddle conveyor shown in FIG. 6 as viewed along line 8-8;

FIG. 9 is an end view of a typical feed zone paddle as viewed along line 9-9 in FIGS. 5 and 6;

FIG. 10 is an end view of a typical reaction zone paddle as viewed along line 10-10 in FIGS. 5 and 6;

FIG. 11 is an end view of a typical end zone paddle as viewed along line 11-11 in FIGS. 5 and 6;

FIG. 12 is a graph of lithium concentration of pulp exiting the reactor versus time after lithium-treated pulp is added at the reactor entrance as an indicator to determine residence time distribution of the pulp for reactors according to the present invention and a conveyor according to prior art;

FIG. 13 is a graph of dispersion index versus paddle rotational speed comparing the axial dispersion of reactors according to the present invention with a prior art conveyor;

FIGS. 14A and B are printouts from a stop action video looking into a conveyor with paddles configured according

to the prior art illustrating pulp mounds and furrows created by relatively large unswept distance;

FIGS. 15A and B are printouts similar to FIGS. 14A and B looking into a reactor according to the present invention illustrating the relatively complete pulp removal and even distribution of pulp;

FIG. 16 is a graph of shaft RPM vs. pulp consolidation pressure for different diameter pulp conveyors;

FIG. 17 is a graph of pulp consolidation pressure vs. critical paddle spacing for a 42% consistency southern softwood pulp;

FIG. 18 is a graph of lithium concentration of pulp exiting the reactor vs. time after lithium-treated pulp is added at the reactor entrance as an indicator to determine the residence time of the pulp in the reactor for certain paddle conveyors;

FIG. 19 is a graph of relatively wide and narrow pulp residence time distributions for certain paddle conveyors;

FIG. 20 is a graph of reactor fill level vs. shaft speed for different paddle conveyors;

FIG. 21 is a graph of pulp residence times vs. shaft speed for different paddle conveyors;

FIG. 22 is a graph of lithium concentration of pulp exiting the reactor vs. time after lithium-treated pulp is added at the reactor entrance for the paddle conveyor of Example 5;

FIGS. 23-25 are printouts from a stop action video looking into the reactor along a line parallel with the shaft to show pulp dispersion as a function of various shaft speeds; and

FIGS. 26-29 are views of different conveying elements for use in accordance with the invention.

Detailed Description of the Preferred Embodiments

[0030] As shown in FIG. 1, the overall apparatus according to the present invention comprises fluffer 10, pulp fiber de-entrainment zone 12, reactor apparatus 14, quenching zone 16 and receiving tank 18. Prior to entering fluffer 10 the pulp passes through a dewatering device (not shown) to control the pulp consistency and a plug screw feeder (not shown) which creates a gas seal to prevent the escape of ozone containing gas.

[0031] Ozone containing gas mixtures which typically, but not necessarily, contain about 1-8% by weight of ozone/oxygen mixture, or 1-4% by weight of ozone/air mixture, are suitable for use in this invention. A preferred mixture is about 6% ozone with the balance predominantly oxygen. Another factor for the bleaching of the pulp is the relative weight of ozone used to bleach a given weight of pulp. Preferably, an amount of ozone is used which will react with about 50% to 70% of the lignin present in the pulp. Also, preferably, the amount of ozone added, based on the oven dried weight of the pulp, typically is from about 0.2% to about 2% to reach the desired lignin levels.

[0032] The pulp entering fluffer 10 is a high consistency pulp, generally having a consistency above 20%. Preferably the pulp consistency entering fluffer 10 is in the range of about 28% to 50% and more preferably between about 35% and 45%, with the consistency being ideally about 40%-42%. Fluffer 10 (also known as a comminuter) decreases the bulk density of the pulp and reduces the size of the flocs (individual bundles of pulp fibers) such that a majority of the pulp fibers are contained in flocs less than about 6mm in diameter and preferably less than about 3mm in diameter. A number of different devices are commercially available for this purpose and their operation is understood by persons skilled in the art.

[0033] After fluffing, the pulp fibers fall vertically through de-entrainment zone 12 and into reactor apparatus 14. The flow of ozone containing gas is countercurrent to the movement of pulp, i.e., pulp moves through the apparatus from fluffer 10 to receiving tank 18, whereas ozone containing gas is added in quenching zone 16 and removed in de-entrainment zone 12. De-entrainment zone 12 includes a frusto-conical or outwardly flared wall portion 20 having a cross-sectional area which increases in the direction of gas flow. This increased area decreases the velocity of the exiting gas to a point where suspended pulp fibers become de-entrained and are not removed with the gas through gas outlet 22. Pulp entering the de-entrainment zone from the fluffer is directed past gas outlet 22 by an internal, cylindrical conduit 24. To prevent back-flow of gas up into fluffer 10, a small flow of ozone containing gas is introduced through the fluffer to maintain flow in the desired direction.

[0034] The falling pulp enters reactor apparatus 14 and is conveyed therethrough while simultaneously reacting with ozone supplied in an ozone containing gas to achieve a uniformly bleached, increased brightness pulp as described below. The pulp leaves the reactor apparatus and falls through quenching zone 16 into receiving tank 18.

[0035] The bleached pulp after ozonation will have a reduced amount of lignin, and therefore, a lower K No. and an acceptable viscosity. The exact values obtained for the K No. and the viscosity are dependent upon the particular processing to which the pulp has been subjected. The resulting pulp will also be noticeably brighter than the starting pulp.

[0036] Quenching zone 16, illustrated in FIG. 2, includes an expansion joint 26 that connects the reactor apparatus to a cylindrical section 28. The expansion joint includes an outer folded metal sleeve and an inner cylindrical sleeve to compensate for thermal expansion of the bleaching apparatus. The details of manufacture and operation of such joints are understood by persons of ordinary skill in the art.

[0037] Gas inlet 30, for introducing the ozone containing gas, is mounted on section 28. An ozone source, such as

an ozone generator (not shown), provides the ozone containing gas. Annular pipe 32 surrounds the lower end of section 28 to supply quenching water. Flange 34 is connected to a water supply. Water from annular pipe 32 is directed into section 28 by nozzles 36 to create a water shower that soaks the pulp and quenches the ozone bleaching reaction on the pulp particles. It is desirable that the quenching occur as uniformly and as quickly as possible in order to preserve the bleaching uniformity achieved in the reactor apparatus. Thus, nozzles 36 are arranged to provide an even, soaking shower of water across the lower end of section 28. Nozzles 36 are also angled downward at an angle of at least 30° with respect to the horizontal and preferably at about 45°, in order to force the pulp down into receiving tank 18 and avoid the formation of a water curtain which would inhibit the free fall of the pulp.

[0038] Receiving tank 18 receives the bleached pulp and water added in the quenching zone. The amount of water added reduces the consistency of the bleached pulp to about 3% to form a pulp slurry. Such a slurry may be easily pumped out of the bottom of the receiving tank through pulp outlet 38 for further processing as desired. A propeller inside the tank, operated by shaft 40, agitates the pulp slurry to maintain an approximately uniform consistency at about 3%. A pulp slurry level is maintained in the tank to allow sufficient agitation time to provide a constant discharge consistency and to provide a gas seal that prevents escape of the ozone containing gas at this end of the apparatus.

[0039] The ozone reactor is depicted as a horizontal, elongated shell in FIG. 1. If desired, the shell may be slightly angled with respect to horizontal to allow the force of gravity to assist in the advancement of the pulp particles. A typical "advancement angle" of up to 25 degrees may be used.

[0040] As explained, in the embodiment of the invention illustrated in FIG. 1, countercurrent flow of ozone containing gas and pulp is contemplated. The ozone containing gas flows from inlet 30 to outlet 22, and the pulp moves in the opposite direction. It is also contemplated that, in an alternative preferred embodiment, ozone containing gas and pulp may move cocurrently through the apparatus. In this case, outlet 22 would become the ozone containing gas inlet and inlet 30 the outlet. Another change from FIG. 1 would be that a de-entrainment zone, such as zone 12, would be incorporated into or adjacent to quenching zone 16. Such modifications are well within the ability of a person of ordinary skill in the art based on the disclosure contained herein and need not be illustrated separately.

[0041] A further preferred alternative embodiment utilizing multiple port gas entry is contemplated. This may include a distribution of inlet ports around quenching zone 16 or may include multiple ports 30A-E disposed in various locations on the reactor shell such as illustrated in FIGS. 3 and 4. Such ports may be used in various combinations and arrangements to maximize ozone consumption and bleaching efficiency.

[0042] Accurate determination of the pulp residence time and residence time distribution allows accurate assessment of the performance of reactors such as the present invention. To determine the pulp residence time for a particular conveyor, an indicator technique has been developed using lithium salts. This technique includes adding a lithium salt, such as lithium sulfate or lithium chloride, as a tracer into the pulp entering the reactor at a particular time. Lithium is used because it is generally not present in the partially delignified pulp. The pulp exiting the reactor is sampled at predetermined time intervals after the lithium salt has been added. The amount of lithium in each sample is measured and graphically depicted as the lithium concentration vs. time.

[0043] FIG. 18 illustrates the residence time distribution for five different paddle conveyors in a 19.5" internal diameter reactor shell where a small amount of lithium-treated pulp is added at the reactor pulp entrance and the samples are taken from the reactor pulp exit at regular time-intervals thereafter. The reactor was operated at a 20% fill level for each conveyor configuration and at a 20 ton per day pulp feed rate. The curves show that the conveyors which are less efficient conveyors, requiring operation at higher RPM to maintain a desired fill level, provide a narrower pulp residence time distribution which is closer to actual plug flow. This control over the pulp residence time distribution contributes to the uniformity of bleaching of the pulp as discussed in greater detail below.

[0044] The pulp residence time distribution ("RTD") can be measured using the lithium indicator technique described above. To measure the RTD, a small amount of the pulp is treated with a lithium salt tracer. The treated pulp is then added all at once to the reactor entrance at time zero (t=0). The concentration of lithium in the pulp is then monitored at the reactor exit by taking discrete pulp samples and measuring the lithium concentration. If the lithium concentration is monitored continuously, a continuous RTD could be obtained.

[0045] The following definitions are taken from Levenspiel, O., The Chemical Reactor Omnibook, OSU Book Stores, Inc., January 1989 (ISBN: 0-88246-164-8). The average pulp residence time is:

$$t_{avg} = \frac{\int_0^\infty C_T \; t \; dt}{\int_0^\infty C_T \; dt}$$

if the tracer concentration, C_T, is obtained in continuous fashion, whereas if C_T is in discrete form, t_{avg} can be approximated by:

$$t_{avg} = \frac{\sum_{i=1}^{n} C_{T,i} \; t_i \; \Delta t_i}{\sum_{i=1}^{n} C_{T,i} \; \Delta t_i}$$

where n samples were obtained for the residence time distribution. The variance, σ^2, of the residence time distribution is a measure of its width. This is given as:

$$\sigma^2 = \frac{\int_0^\infty C_T t^2 \; dt}{\int_0^\infty C_T \; dt} - (t_{avg})^2$$

and can be approximated for discrete distributions as:

$$\sigma^2 = \frac{\sum_{i=1}^{n} C_{T,i} t_i^2 \; \Delta t_i}{\sum_{i=1}^{n} C_{T,i} \Delta t_i} - (t_{avg})^2$$

[0046] For a perfect plug flow vessel, the variance would be zero. The larger the variance, the wider the pulp residence time distribution, and hence more axial mixing occurs. Further, a wider residence time distribution will lead to less uniform bleaching, with some fibers overbleached and some underbleached. This can compromise bleached pulp quality and may consume excess bleach chemical and lead to pulp degradation. Thus, the variance can be used as a measure of bleaching uniformity, with a small number being preferred.

[0047] In order to compare bleaching uniformity between experiments having different average residence times, it is necessary to normalize the variance. The dispersion index ("DI") is defined as:

$$DI = \frac{100\,\sigma^2}{(t_{avg})^2} = 100 \left[\frac{\int_0^\infty C_T\, t^2\, dt}{\int_0^\infty C_T\, t\, dt} - 1 \right]$$

for continuously measured residence time distributions. This can be approximated as:

$$DI = \frac{100\,\sigma^2}{(t_{avg})^2} = 100 \left[\frac{\sum_{i=1}^{n} C_{T,i}\, t_i^2\, \Delta t_i}{\sum_{i=1}^{n} C_{T,i}\, t_i\, \Delta t_i} - 1 \right]$$

for discrete distributions. The dispersion index is proportional to the variance. This normalized variance, which measures deviation from plug flow and hence is a measure of axial dispersion, will be used as an indicator of bleaching uniformity. A value of zero would indicate perfect plug flow. Large values indicate poor bleaching uniformity.

[0048] To illustrate the concept, consider FIG. 19 in which the experimentally determined pulp residence time distribution is plotted for two different paddle designs: 60 degrees full pitch with overlapping paddles, and 240 degree quarter pitch with nonoverlapping paddles. In each case the pulp production rate was about 20 tpd. The paddle shaft rotation speeds were 25 and 90 rpm, respectively. Note especially that, although the average residence times were about the same (49 and 45 seconds, respectively), the width of the distributions are very different.

[0049] In the first case (60 degree design), about 10% of the pulp has a residence time less than 32 seconds while another 10% has a residence time greater than 71 seconds. For the second case (240 degree design), the corresponding range is 36 seconds and 55 seconds. The wider range is indicated by the higher dispersion index, 8.2 vs. 2.6. The pulp with the shortest residence time will be underbleached and that with the highest will be overbleached, relative to the average amount of bleaching. This effect would be larger for the case with the higher dispersion index.

[0050] The construction and operation of reactor apparatus 14 will now be explained in detail. As shown in FIG. 1, reactor apparatus 14 includes upper and lower sections 14A and 14B. It should be understood, however, that two sections are not a requirement of the present invention. A reactor apparatus according to the present invention may be designed in a single section or in multiple sections depending on various factors, such as the size and capacity of the apparatus and the space available for installation.

[0051] Each section 14A and 14B of the reactor includes a generally cylindrical shell 42A and 42B, respectively. Upper shell 42A defines a pulp inlet 44A and a pulp outlet 46A. Pulp inlet 44A is connected to and communicates with de-entrainment zone 12. Lower shell 42B defines a pulp inlet 44B, which is connected to and communicates with upper pulp outlet 46A and a lower pulp outlet 46B connected to and communicating with the expansion joint 26 of quenching zone 16.

[0052] Each section 14A and 14B also contains a rotating conveying and dispersing member for conveying the pulp through the shells from inlet to outlet, while at the same time radially dispersing the pulp around the radius of the shell to distribute it across the entire cross-section. In a preferred form, this member comprises rotating shafts 48A and 48B with a plurality of radially extending paddles 52A, 52B, shown in FIGS. 5-8. Shafts 48A and 48B are rotated by motors 50A and 50B, respectively, shown in FIG. 1.

[0053] The CEMA standard (discussed in the Background section) sets forth certain paddle blade sizes for given diameters. In this invention those sizes will be referred to as "standard" size. To achieve high pulp/gas contact, large paddles having an area of twice the standard size can be used. However, such large paddles also increase the conveying rate significantly. For increased mixing effects, small paddles having an area of about half that of a standard paddle, can be used.

[0054] The paddle angle can also be varied as desired. While a 45° angle may be preferred for maximum axial movement, other angles can be used to increase the residence time of the pulp in the reactor as explained below.

[0055] The paddle spacing is important to avoid bridging of the pulp as it travels through the reactor, since bridging detracts from obtaining uniform pulp bleaching. Bridging (i.e., the forward movement of pulp in large clumps or masses which have arched between successive paddles) is caused by compaction and consolidation forces exerted on the pulp which increase pulp density and the ability of the pulp to adhere to itself.

[0056] For any particular conveyor design, one skilled in the art can calculate the estimated consolidation forces or stresses on the pulp from the operating characteristics of the conveyor utilizing the inertial force from the centrifugal movement of the paddles and the static head from the weight of the pulp therein. The consolidation pressures for standard paddle conveyors of different diameters when operated at a fill level of about 25% and at various RPMs are illustrated in FIG. 16. For example, a 61 cm (2') diameter paddle reactor operated at 60 RPM would generate an estimated consolidation pressure of about $2{,}4{\cdot}10^5$ N/m^2 (35 psi).

[0057] For the particular pulp to be bleached, one can measure pulp strength versus consolidation pressure and then estimate how far apart the paddles must be to prevent bridging (i.e., the length beyond which the pulp cannot support its weight and will break into smaller segments). For 42% consistency southern softwood pulp, FIG. 17 illustrates a graphical representation of calculated critical (minimum) paddle spacing vs. consolidation pressure. For the particular example, a consolidation force of $2{,}4{\cdot}10^5$ N/m^2 (35 psi) suggests a minimum paddle spacing of about 15,2 cm (6 inches).

[0058] Paddle spacing is determined by measuring a straight line distance between the two closest points of adjacent paddle edges. For a 240° quarter pitch paddle conveyor, the two closest points are the trailing edge of the first paddle and the leading edge of the fourth paddle. For other configurations, such as 60° full pitch, the two closest points would be the trailing edge of the first paddle and the leading edge of the second paddle. For any particular paddle configuration, this distance must be greater than the critical arching dimension of the pulp to avoid bridging. However, while spacing must be such that briding is avoided, it should not be such that the maximum unswept distance valves explained below6 in connection with Example 1 are exceeded.

[0059] In the present invention, in order to provide improved ozone bleaching effectiveness and uniformity, a unique arrangement of paddles has been devised. Referring to FIGS. 5 and 6, each shaft 48A, 48B includes thirty-two paddle positions, with each position including a single paddle (except for the thirty-second which includes four paddles). The paddles are designated in FIGS. 5 and 6 according to their position, e.g., a paddle on the lower shaft at position 28 is designated 52B-28. For convenience of illustration, repetitive portions of the shafts in FIGS. 5 and 6 have been broken away such that all paddle positions are not shown.

[0060] The paddles on each shaft may be divided into three general zones: feed zone, reaction zone and end zone. The first paddle of the feed zone, 52A-1 and 52B-1, is located under pulp inlets 44A and 44B, respectively. The end zone paddles, 52A-32 and 52B-32, are located immediately after pulp outlets 46A and 46B, respectively. On upper shaft 48A, the feed zone comprises paddles 52A-1 through 52A-9 and the reaction zone comprises paddles 52A-10 through 52A-31. On lower shaft 48B, the feed zone comprises only paddles 52B-1, -2 and -3, and the reaction zone comprises paddles 52B-4 through 52B-31. The paddles in the feed and reaction zones are preferably arranged at 240° spacings in a helical quarter-pitch pattern. The end zone includes only paddle position -32. Four paddles are located at this position with a reverse angle (shown in FIG. 11 as preferably about 45°).

[0061] As shown in FIGS. 9-11, each paddle comprises a blade 54 and support 56. The feed zone paddles are illustrated in FIG. 9. These paddles are standard full size CEMA paddles, that is, blades 54 have the same surface area as specified by CEMA for a standard paddle in a paddle conveyor having the same diameter as the reactor shells 42A and 42B according to the present invention. Thus, as illustrated in FIG. 9, dimension 59 is approximately the same as for a standard CEMA paddle. As also illustrated in FIG. 9 and shown in Table I, contrary to CEMA teachings the paddle angle (Θ) decreases along the shaft in the feed zone.

TABLE I -

FEED ZONE PADDLE ANGLES			
UPPER SHAFT 48A		**LOWER SHAFT 48B**	
Paddle Position	Paddle Angle Θ	Paddle Position	Paddle Angle Θ
52A-1	45°	52B-1	45°
52A-2	45°	52B-2	40°
52A-3	45°	52B-3	35°
52A-4	45°		
52A-5	43°		

TABLE I - (continued)

FEED ZONE PADDLE ANGLES			
UPPER SHAFT 48A		**LOWER SHAFT 48B**	
Paddle Position	Paddle Angle Θ	Paddle Position	Paddle Angle Θ
52A-6	41°		
52A-7	39°		
52A-8	37°		
52A-9	35°		

[0062] The paddle angle (Θ) is measured from the centerline 58 of shafts 48A and 48B. Table I gives preferred angles for the feed zone paddles wherein the paddle angle in the reaction zone is preferably about 45°. Generally, paddle angles between about 30° and 50° are useful for the reaction zone of the present invention, in which case, the paddle angles in the feed zone would be adjusted according to the teachings contained herein.

[0063] The feed zones provide means for maintaining the fill level of the pulp in the reactor. The fill level of the pulp in the reactor should generally be between about 10 to 50% and preferably about 15 to 40%, with the fill level being most preferably about 20-25%. Fill level refers to the percentage of the volume of the reactor occupied by pulp. However, the pulp does not lie in the bottom of the reactor, but is continuously dispersed throughout the entire volume of the reactor. Maintenance and control of the fill level is important to ensure that sufficient pulp is present to be adequately dispersed in order to efficiently consume the ozone without being over bleached or under bleached.

[0064] A particular design for the feed zone is provided because the pulp entering the reactor has had its bulk density significantly reduced in fluffer 10. Thus, the pulp is subject to compaction due to the force of the paddles pushing it through the reactor. Without the feed zone according to the present invention, the fill level of pulp in the reactor would decrease from the inlet to the outlet due to the compaction forces exerted by the paddles or other conveying elements. To alleviate this problem, the feed zone of the present invention has a conveying rate higher than the subsequent reaction zone. The conveying rate of the feed zone is tailored by using larger paddles at gradually flatter angles, as illustrated in FIG. 9 and Table I, to first provide a relatively high conveying rate which subsequently decreases to be approximately equal to the conveying rate of the reaction zone. In this manner, the entering pulp, with the lowest bulk density, is conveyed the fastest and the conveying rate decreases gradually as the bulk density increases due to compaction forces. An approximately constant fill level is thereby maintained. In lower reactor section 14B, the feed zone includes only three paddles because the reduction in bulk density is due only to the pulp falling through outlet 46A and inlet 44B and is thus much less than that provided by fluffer 10.

[0065] To illustrate the effects on fill level and pulp residence time by varying the paddle design, FIGS. 20 and 21 are presented. A shorthand notation is used to designate the various paddle configurations in the figures: the first number is the angular spacing of the paddles; this number is followed by the letter, F, H, or Q which stand for full pitch, half pitch or quarter pitch paddle arrangements, respectively. Next, two letters indicate the paddle size: SD-Standard size (i.e., CEMA standard for full pitch conveyors); LG-large (2X standard) size; SM-small (1/2 standard) size.

[0066] For the conveyors listed in FIGS. 20 and 21, the pulp feed was 20 oven dry tons per day (ODTPD), the paddle angle to the shaft was 45° unless otherwise designated, and a 6% ozone/oxygen mixture at 35 SCFM was again utilized. The gas residence time was about 60 seconds. The pulp had a consistency of about 42% so that the ozone application is 1% on O.D. pulp. The data suggests that fill levels between about 20 and 40% at a shaft speed of 40 to 90 RPM and a pulp residence time of about 40 to 90 seconds is preferred when an ozone application of about 1% on oven dry pulp is utilized. In addition, these graphs show how a change in shaft RPM can affect fill level, pulp residence time and ozone conversion. In the invention, a gas residence time of at least about 50% or more of the residence of the pulp is useful, with at least about 67% being preferred.

[0067] In FIGS. 20 and 21, percent ozone conversion is indicated by a numerical value associated with certain data points on the graphs. These numerical values are also listed in Table X of Example 10 along with the respective paddle design and reactor operating conditions. These data suggest that higher fill levels can be achieved by reducing the pitch of the conveyor, utilizing smaller paddles, or using a flatter paddle angle. In particular, dramatic reductions in conveying efficiencies are obtained by merely changing the paddle angle from 45° to 25°.

[0068] It is in the reaction zones of the present invention that the bleaching reaction with the ozone primarily occurs; although bleaching will occur to varying degrees throughout reactor apparatus 14, due to the fact that ozone and pulp are present together throughout. The paddles of the reaction zones are specifically designed to maximize ozone consumption and bleaching uniformity while conveying the pulp through the reactor. To this end, the reaction zone paddles are smaller than standard full size CEMA paddles for conveyors of the same diameter. FIG. 10 illustrates a typical reaction zone paddle, wherein dimension 60 is preferably about one-half standard CEMA size and the paddle angle

is approximately 45°. Therefore, the preferred arrangement of the paddles in the reaction zone is 240° spacing in a helical quarter-pitch pattern with half-standard or small size paddles (240-Q-Sm).

[0069] Although a paddle conveyor is preferred, other conveyor configurations can be used. A useful reactor can be made using a screw flight conveyor having so-called "cut and folded" flights, shown at 152 in FIG. 26. The open portions 154 of the flight 156 permit the gas to be directed therethrough while the folded portions 158 cause both radial distribution of the gas and the appropriate lifting, tossing, displacing and radial dispersion of the pulp in the gas as the pulp is advanced to obtain the desired uniform bleaching.

[0070] Alternatively, a series of wedge shaped flights 160 (shown in cross-section in FIG. 29) or elbow shaped lifter elements 162 (shown both in side view and cross-section in FIG. 28) are also useful for radially dispersing asnd conveying the pulp through the gaseous bleaching agent.

[0071] Ribbon mixers 164 (FIG. 27) present a further useful alternative. An inclined reactor utilizing a totally flat ribbon flight, i.e., one having infinite pitch, with angles instead of flat blades, conveys the fiber particles with a similar lifting and dropping action to effect the desired gas-pulp contact and reaction. The inclined ribbon design results in plug-like flow advancement of the dispersed pulp with little backmixing, but this design cannot be adjusted as easily as the paddle conveyor.

[0072] A combination of paddles and cut and folded flights can be used, if desired, and if designed in accordance with the foregoing. However, typical, unmodified full screw flight conveyors are not acceptable, because they generally "push" the pulp therethrough, rather than lifting, tossing and displacing it, as does the paddle conveyor and alternatives described above.

[0073] It has been discovered in accordance with the invention that two important factors in ozone bleaching of high consistency pulp are (1) that the pulp be distributed throughout the ozone containing gas within the reactor and (2) that, to the greatest extent possible, each pulp fiber reside in the presence of ozone exactly as long as every other pulp fiber. The first factor is referred to herein as radial dispersion and the second factor as plug flow, which results from minimum axial dispersion. It has further been unexpectedly discovered that standard prior art paddle conveyors are not capable of at once satisfying both of these two important factors.

[0074] Reactor apparatus 14 according to the present invention maximizes radial dispersion of the pulp such that a majority of the pulp fibers are suspended in the ozone containing gas as they are conveyed through the reactor shells. This means that at any given time during reactor operation, the pulp particles are dispersed across the entire cross-section of the reactor shell with a portion being located around the entire circumference, including the top of the shell, due to the action of the paddles in lifting and tossing the pulp to radially disperse it. Such radial dispersion is in direct contrast to traditional conveyors wherein a majority of the particles being conveyed lie in the bottom of the conveyor. Additionally--and without detracting from the radial dispersion described above --the present invention minimizes axial dispersion of the pulp as it is conveyed through the reactor shell to provide a narrow pulp particle residence time distribution, which, together with the radial dispersion, accounts for the uniform and efficient bleaching of the present invention.

[0075] The radial dispersion of the pulp is dependent in part on the centrifugal force imparted to the pulp by the conveyor. Other important factors include, for example, the area and angle of the paddles. The area and angle determine how much of the pulp in the reactor is lifted and tossed, but the amount of centrifugal force determines the degree of dispersion of the pulp which is lifted and tossed. Degree of dispersion refers to the tendency of the pulp to be propelled toward the periphery of the reactor as opposed to simply sliding off of the paddles. In a rotating system such as the pulp bleaching reactor of the present invention, the centrifugal force acting on the pulp is dependent upon the rotational speed and the diameter of the rotating paddles. Based on the teachings of the present invention and the rotational speeds and diameter disclosed herein, a person of ordinary skill in the art could select an appropriate diameter and rotational speed to achieve results comparable to those discussed herein for any size device.

[0076] While radial dispersion may be increased using standard prior art paddle conveyors operated at higher than normal rotational speeds, two negative effects arise from the increased speed in a prior art conveyor: First, axial dispersion of the pulp particles increases dramatically. Second, the pulp particles are conveyed at higher speeds such that it is impossible to maintain fill level and residence time in a reactor of reasonable scale. These negative effects defeat the utility of prior art structures as ozone bleaching devices. In addition, the lack of appreciation of these effects appears to be the reason for the absence of commercially successful ozone bleaching devices in the prior art.

[0077] In order to correct these two negative effects, the conveying efficiency of the reactor according to the present invention has been reduced relative to prior art conveyors, while improving the axial dispersion performance to approach plug flow over a full range of rotational speeds. This is accomplished by the combination of reduced paddle size, increased helical paddle spacing and reduced pitch. These modifications according to the present invention provide the completely unexpected results of minimizing axial dispersion while reducing the conveying rate to maintain fill level and residence time at high rotational speeds allowing radial dispersion of the pulp. The present invention thus achieves a near perfect plug flow of radially dispersed pulp particles.

Example 1

[0078] The following example illustrates the improved radial and axial dispersion characteristics of the present invention over traditional prior art conveyors. The conveyor/reactor used in this example included a shell 6,1 m (twenty feet) long with an internal diameter of 49,5 cm (19.5"). Full pitch for the conveyor was 48,3 cm (19") (full pitch is equal to diameter of the conveying elements). The pulp used in the example was partially bleached softwood pulp having a consistency of approximately 42%. The reactor was capable of being modified to use different paddle configurations as shown in Table II.

[0079] As previously explained, a key factor in bleaching uniformity is the axial dispersion of the pulp. Axial dispersion may be quantified as the residence time distribution, indicated by the Dispersion Index (DI) in Table II. Perfect plug flow is represented by a DI of zero as also previously explained.

[0080] Run A utilized a reactor with paddles arranged according to the reaction zone of the present invention having 240° helical spacings at quarter pitch with half-standard (small) size paddles (240-Q-Sm). Run B utilized a modified paddle conveyor according to a lesser preferred embodiment of the present invention, with standard size paddles arranged at 120° spacings in a helical half-pitch pattern (120-H-Sd). Runs C and D utilized a conveyor configured according to the prior art with paddles at 120° helical spacings, full pitch and standard size paddles (120-F-Sd). The runs were devised to compare dispersion characteristics and the effect on fill level and residence time for the present invention and the prior art.

TABLE II

		Paddle Type							
Run	Paddle Spacing (deg)	Pitch	Paddle Size	Paddle Angle (deg)	Feed Rate (ODTPD)	Paddle Rotational Speed (RMP)	Pulp Fill Level (%)	Avg. Res. Time Pulp (sec.)	Dispersion Index
A	240	Quarter	Small	45	18	90	18	45	2.6
B	120	Half	Stnd	45	20	50	19	44	4.8
C	120	Full	Stnd	45	20	60	23	52	8.9
D	120	Full	Stnd	45	20	90	11	25	12.5

[0081] In Run A, according to the present invention, the relatively high rotational speed (90 rpm) provides radial

dispersion of the quality required by the invention to expose a majority of the pulp particles to the ozone containing gas. The DI under these operational conditions is 2.6. This is an excellent result which indicates that pulp movement through the reactor approaches plug flow, even while being radially dispersed. Also, the fill level and average residence time resulting from operation at that speed are sufficient to provide good ozone consumption and bleaching uniformity.

[0082] Run B illustrates a lesser preferred embodiment of the present invention. This embodiment is lesser preferred primarily due to the fact that in order to maintain the fill level and residence time in the desired ranges the rotational speed must be reduced to about 50 rpm. At this rotational speed the radial dispersion is not of the same quality as with the preferred 240-Q-Sm design, but it is still possible to obtain the radial dispersion necessary for acceptable ozone consumption and brightness increase. However, due to the low DI of 4.8, the 120-H-Std design does have a significant advantage over the prior art as shown in Runs C and D. The 4.8 DI indicates that pulp movement is still approaching plug flow, although, again not as closely as the preferred 240-Q-Sm design.

[0083] Runs C and D show the results if a typical prior art paddle conveyor is operated under conditions attempting to achieve the results of the present invention. In Run C, the prior art device was operated at 60 rpm in order to maintain the fill level and average pulp residence time approximately the same as with the present invention. While this speed may allow radial dispersion similar to Run B, the DI is substantially higher than with the present invention. At such a high DI it is not possible to achieve satisfactory uniform bleaching and some of the pulp may be severely degraded due to over bleaching. In an attempt to achieve improved radial dispersion, the rotational speed of the prior art conveyor was increased in Run D to 90 rpm. However, not only do the fill level and average residence time fall to unacceptable levels, the DI increases further, to about 12.5.

[0084] In order to understand the teachings of the present invention, as evidenced in Table II, the relationship between radial dispersion and axial dispersion in ozone pulp bleaching according to the present invention must be understood. This relationship may be explained as follows: Once a minimum rotational speed is reached, such that the pulp is at least minimally radially dispersed and not merely pushed along the bottom of the conveyor as in standard prior art conveyors operated at normal prior art rotational speeds, the primary factor affecting bleaching uniformity becomes Dispersion Index. After this minimum point, increased radial dispersion will increase uniformity to a degree, but if pulp movement through the reactor does not approach plug flow any gains due to increased radial dispersion will be effectively lost. For these reasons, as is evident from Table II, although capable of radial dispersion, prior art paddle conveyors are unsuited for ozone pulp bleaching.

[0085] FIGS. 12 and 13 summarize the data obtained by applicants in their tests comparing the dispersion characteristics of the prior art with the present invention. Although the pulp used to obtain the dispersion data was softwood pulp, dispersion characteristics are not particularly influenced by pulp type. Therefore hardwood and softwood pulps having the same consistency can be expected to exhibit the same dispersion characteristics. FIG. 12 graphically portrays the difference between a DI of 2.6 and 4.8 according to the present invention and a DI of 8.9 in the prior art as shown in runs A, B and C of Table II.

[0086] For example, to achieve a desired target brightness of 63% GEB in a hardwood pulp having an entering brightness of 41% GEB with an ozone concentration of 6 wt% in the ozone containing gas, the residence time for the pulp in the reactor according to the invention should be about 43 seconds. With this target, an acceptable brightness range would be approximately 60-66% GEB. This range of brightness is obtained with residence times between about 30 to 59 seconds. Pulp having a brightness over 66% GEB is overbleached. The presence of a substantial amount of such overbleached pulp would significantly decrease the pulp strength. As illustrated in FIG. 12, at a DI of 2.6, approximately 95% of the pulp falls within the desired residence times. Less than 3% of the total pulp is overbleached. Even in the lesser preferred embodiment of the invention, 88% falls within the desired range. In contrast, the long "tail" on the prior art distribution curve for the prior art conveyor indicates a much greater amount of pulp having a residence time in excess of about 59 seconds. In fact, in the prior art conveyor only about 76% falls within the desired range, and 22% of the pulp has a residence time greater than 59 seconds. The pulp experiencing such high residence times will become overbleached, resulting in nonuniformity, cellulose degradation and loss of strength--detriments associated with ozone bleaching of high consistency pulp in the prior art.

[0087] In FIG. 13, the Dispersion Indices for the prior art conveyor are compared to the preferred 240-Q-Sm reactor and the less preferred 120- H-Std reactor of the present invention over a wide range of operational speeds. It can be seen that at low speeds the DI for all three are similar, although still slightly lower for the present invention. However, at low speeds, e.g. 25 rpm, the centrifugal force is not sufficient to provide adequate radial dispersion; the pulp is conveyed mainly along the bottom of the reactor, resulting in inefficient pulp-gas contact so that fibers are not bleached uniformly even though the DI is low. As speed is increased to achieve radial dispersion, the DI of the present invention remains relatively constant, rising to no greater than about 5-7 at about 125 rpm. In contrast, the DI of the prior art conveyor increases rapidly to greater than 20.

[0088] One reason for the poor axial dispersion characteristics of the prior art is the existence of a relatively large unswept distance between each paddle, even though the paddles are helically spaced at more frequent intervals and are larger than those of the present invention. The large unswept distances between paddles result in large mounds

or ridges of pulp being created in the bottom of the prior art 120-F-Std conveyor as shown in FIG. 14.

[0089] FIGS. 14A-B and 15A-B were generated using a 17" diameter conveyor having a plexiglass shell. This conveyor did not have a continuous pulp feed. Instead, the shell was filled with pulp and the conveyor ran until pulp stopped exiting at the end. The stop-action video pictures used for FIGS. 14 and 15 were taken at that point. All of the pulp shown in FIGS. 14 and 15 is sitting on the bottom of the rounded plexiglass shell, essentially without movement in any direction (pulp which appears to be in the air is actually lying on the upwardly curved portion of the back of the clear shell).

[0090] Any differences between FIG. 14A and FIG. 14B, and between FIG. 15A and FIG. 15B, are accounted for by the relatively less clearance used between the end of each paddle and the plexiglass shell in FIGS. 14A and 15A. In FIGS. 14A and 15A this clearance was about 0,3-0,6 cm (1/8 - 1/4 inch). In FIGS. 14B and 15B the clearance was 0,6-0,95 cm (1/4 - 3/8 inch). Based on the teachings of the present invention a person of ordinary skill in the art will appreciate the effect such variations in clearance would have on the apparatus according to the invention.

[0091] The mounds of pulp shown in FIGS. 14A and B are dead zones, unacted upon by the paddles. Due to the relatively large size of the mounds, a large number of pulp particles become "trapped" in the mounds, while others are moved on by the paddles. The large size of the mounds means that a relatively long period of time is required for all of the pulp particles in a mound to be cycled through the mound and completely displaced by new particles.
Displacement allows the original particles of a mound to move to the next mound and thus through the conveyor. This long cycle period for each mound results in the long tail on the prior art distribution curve in FIG. 12. The presence of a large amount of pulp in mounds, unacted on by paddles, also reduces radial dispersion.

[0092] In contrast, FIGS. 15A and B illustrate the pulp in a reactor according to the present invention with a 240-Q-Sm paddle arrangement. FIGS. 15A and B show that the present invention provides a relatively more uniform distribution of pulp, without the distinct mounds and furrows of the prior art as shown in FIGS. 14A and B. Individual pulp particles move more uniformly through the present invention, without significant numbers being delayed in mounds between paddles. The low Dispersion Indices of the present invention are the result.

[0093] The unswept distance may be calculated for any paddle conveyor, providing a useful comparison between the present invention and the prior art. Referring to FIG. 6, paddles 52B-28 and 52B-29, it can be seen that unswept distance Y may be calculated as follows:

$$Y = X - B \cos \Theta$$

where X is the centerline distance between adjacent paddles; B is the paddle width, e.g., dimension 60 in FIG. 10; and e is the paddle angle as shown in FIGS. 9 and 10.

[0094] Furthermore, it has been observed by the applicants that the dimensions of the prior art standard CEMA paddles generally adhere to the following relationship:

$$B = 0.31\ D$$

where B is again the paddle width; and D is the diameter of the conveyor. This relationship was initially calculated based on CEMA Standard No. 300-008 for conveyor diameters between 15,2-61 cm (6 and 24 inches) and is believed to hold true over the full range of diameters. It follows that for small paddles, i.e., one-half standard size, the relationship is:

$$B = 0.155\ D$$

[0095] Also, X may be expressed in terms of diameter D (diameter is equal to pitch) as follows:

$$X = D / ppp$$

where ppp is the number of paddles per pitch, in other words, the number of paddles along the shaft in any segment equal in length to the diameter. For example, in a 240-Q-Sm reactor conveyor according to the present invention, ppp = 6. In the 120-F-Std conveyor according to the prior art, ppp = 3.

[0096] Unswept distance Y, therefore, may be expressed in terms of diameter D for any given paddle configuration, based on only paddle angle Θ. Using a paddle angle of 45°, the unswept distance Y in the reaction zone for the present invention is 0.06D. The unswept distance for the prior art conveyor is 0.11D. As such, paddle configurations according to the present invention having an unswept distance less than about 0.11D will provide improved results. Preferably

the unswept distance is less than about 0.09D and more preferably about 0.06D or less. Certain paddle configurations will yield negative unswept distance values, indicating overlapping paddles. Such overlapping configurations may be acceptable; however, overlapping paddles also present other difficulties with regard to pulp bridging between paddles. The requirements for paddles spacing to prevent bridging are discussed in detail above and in Example 12, and must be seriously considered when dealing with overlapping paddle configurations.

Examples 2-14

[0097] The scope of the invention is further described in connection with Examples 2-14, which are set forth for purposes of illustration only and which are not to be construed as limiting the scope of the invention in any manner. Unless otherwise indicated, all chemical percentages are calculated on the basis of the weight of oven dried (OD) fiber. Also, one skilled in the art would understand that the target brightness values do not need to be precisely achieved, as GEB values of plus or minus 2% from the target are acceptable. The feed pulp in these examples is fluffed oxygen bleached pulp having a K No. of about 10 or less, a viscosity of greater than about 13 cps, a consistency of about 42% and an entering brightness generally in the range of about 38-42% GEB. This pulp is acidified to a pH of about 2 before being introduced into the reactor of the invention.

[0098] In Examples 2-11 and 14 that follow, the reactor was a 49,5 cm (19.5") internal diameter, 6,1 m (20 foot) long shell having conveying intervals therein as defined. Full pitch for this reactor is 48,3 cm (19"), and feed rate unless otherwise specified was generally about 20 tons per day of the 42% consistency partially bleached softwood pulp described above. Countercurrent ozone gas flow was utilized unless otherwise mentioned. The data in Examples 12 and 13 was obtained in a 43,2 cm (17") conveyor.

Example 2

[0099] It has been found that utilizing a cut and folded screw flight design obtains results somewhat similar to those obtainable through the use of a paddle conveyor. A cut and fold screw conveyor reactor, and one embodiment of a paddle type conveyor reactor of the present invention utilizing similar feed rates of pulp, rotational speed and gas residence time were compared. As is evidenced by the results illustrated in Table III, use of the paddle configuration resulted in an ozone conversion about 18 percent higher than that obtained with the cut and fold screw conveyor reactor. The paddle reactor also exhibited an improved (i.e., lower) dispersion index, indicating a pulp movement closer to plug flow.

TABLE III

Type of Conveyor	Feed Rate ODTPD	Conveyor Rotational Speed (RPM)	Ozone Appl. on Pulp (%)	Residence Time Gas (S)	Residence Time Pulp (S)	Fill Level (%)	Ozone Conversion (%)	Change in GE Brightness (%)	DI
Screw	11	20	1.0	25	115	27	72	10	6.9
Paddle	11	30	0.9	33	169	40	90	12	1.9

Example 3

[0100] In a comparison between a conventional screw type conveyor reactor, and a paddle conveyor reactor, the

paddle type conveyor configuration was specifically designed to achieve a lower conveying rate than the screw. This allowed the paddle conveyor to be run at significantly higher rotational speed, while maintaining a fill level equivalent to the screw. Closed flight screws, while providing close to plug flow with low DI values, do not disperse the pulp into the gas. As previously explained, it is not enough to obtain plug flow unless the pulp is also dispersed, since plug flow of nondispersed pulp also results in non-uniform bleaching.

[0101] Table IV illustrates that the significantly greater rotational speed of the paddle conveyor resulted in a 24 percent increase in ozone conversion in the paddle conveyor. Table IV also illustrates how paddle configuration can be specifically designed to achieve excellent gas-fiber contacting in contrast to a conventional conveying configuration.

TABLE IV

					Residence Time				
Type of Conveyor	Feed Rate (ODTPD)	Conveyor Rotational Speed	Gas Flow Rate	Ozone Appl. on Pulp (%)	Gas Pulp (S)	(S)	Fill Level (%)	Ozone Conver-sion (%)	Change in GE Bright-ness (%)
Screw	12	21	34	1.0	46	71	18	73	13
Paddle	18	90	35	0.9	46	45	18	97	15

Example 4

[0102] The design of the paddles on the paddle conveyor was altered in order to allow higher RPM operation while maintaining a constant fill level of 20 percent at a feed rate of about 18 to 20 oven dried tons per day, thereby keeping pulp residence time constant. The design alteration yielded a significant increase in ozone conversion as evidenced by Table V. As shown by this example, alteration of the full pitch conventional paddle arrangement as taught by this invention dramatically improves gas-fiber contacting by allowing reasonable fill level operation at higher RPM.

Example 5

[0103] As discussed, a preferred paddle configuration is a 240 degree, one quarter pitch design using paddles having dimensions one half of the CEMA standard mounted at a 45 degree conveying angle. Use of this configuration provides a high ozone conversion efficiency as illustrated in the paddle conveyor of Example 3. Surprisingly, use of this configuration provides the additional benefit of maintaining a constant residence time distribution over a broad range of operating conditions and fiber residence times, thus ensuring uniformity of bleaching. This is illustrated by the lithium indicator data shown in FIG. 22.

Example 6

[0104] A comparison of counter-current and cocurrent gas flow resulted in favorable results for both directions of gas flow. An increase in efficiency, as illustrated in Table VI, resulted from the use of counter-current gas flow.

TABLE V

Paddle Spacing (deg)	Paddle Type: Pitch	Paddle Type: Paddle Size	Paddle Type: Paddle Angle (deg)	Feed Rate (ODTPD)	Paddle Rotational Speed (RPM)	Fill Level (%)	Res. Time Pulp (sec.)	Ozone Conversion @35SCFM (%)	Change in GEB Brightness
60	Full	Stnd	45	20	25	21	49	71	12
120	Half	Stnd	45	20	50	19	44	92	15
240	Quarter	Small	45	18	90	18	45	97	15

TABLE VI

Gas Flow	Feed Rate (ODTPD)	Paddle Rotational Speed (RPM)	Gas Flow Rate (SCFM)	Ozone Appl. On Pulp (%)	Ozone Conversion (%)	Change in GEB Brightness (%)
Counte-current	20	50	35	0.9	92	15
Co-current	20	50	35	0.9	87	14

Example 7

[0105] The gas residence time within the reactor was adjusted to bring it to a level similar to that of the pulp residence time. The results, illustrated in Table VIII below, demonstrate the nearly complete ozone conversion accomplished while attaining an excellent level of brightness increase.

TABLE VII

Feed Rate (ODTPD)	Paddle Rotational Speed (RPM)	Gas Flow Rate	Ozone Appl. On Pulp (%)	Residence Time		Ozone Conversion (%)	Change in GEB Brightness (%)
				Gas	Pulp		
20	40	35	0.9	42	57	95	15
19	40	50	1.1	29	57	80	14
20	40	95	1.3	15	57	74	16

Example 8

[0106] By altering the rotational speed of any particular configuration of paddles, the pulp residence time can be controlled so as to attain the desired target for ozone conversion, as illustrated below in Table VIII. The data presented therein is for a 240° Q-SD 45° conveyor.

TABLE VIII

Feed Rate (ODTPD)	Paddle Rotational Speed (RPM)	Gas Flow Rate (SCPM)	Fill Level (%)	Residence Time Pulp (sec.)	Ozone Conversion (%)	Change in GEB Brightness (%)
20	90	36	14	32	86	11
19	60	34	18	43	93	11

Example 9

[0107] The following tests were conducted to show the effects of a change in paddle design for a constant feed and same shaft RPM.

TABLE IX

Paddle Type									
Paddle Spacing (deg)	Pitch	Paddle Size	Paddle Angle (deg)	Feed Rate (ODTPD)	Paddle Rotational Speed (RPM)	Fill Level (%)	Res. Time Pulp (sec.)	Pulp Conversion (%)	Change in GEB Brightness (%)
240	Quarter	Stnd	45	19	60	18	43	93	11
240	Quarter	Small	45	18	60	34	85	99	15

These data show that a change to smaller paddles substantially reduces conveying efficiency while increasing fill level and pulp residence time in the reactor. These changes have resulted in improved bleaching performance as measured by ozone conversion and change in brightness.

[0108] Additional variations are shown in Example 10. From this information, one skilled in the art can best determine how to design and run a particular paddle conveyor reactor for the desired degree of bleaching on a particular pulp.

Example 10

[0109] The following Table X summarizes the specific paddle design and operating conditions which were used to generate FIGS. 20 and 21. A pulp feed of 20 TPD and a reactor shell size of 49,5 cm (19.5") I.D, were utilized, at a target fill level of about 20% for the first five rows of Table X. Again, a 6 weight percent ozone bleaching agent was used at a flow rate of 35 SCFM to apply about 1% ozone on OD pulp.

TABLE X

Paddle Design				Operating Conditions		Results	
Spacing	Pitch	Size	Angle	RPM	Fill Level Actual (%)	Pulp Res. Time (S)	Ozone Conversion (%)
60	Full	Std.	45	25	21	49	71
120	Full	Large	45	40	17	40	85
120	Half	Std.	45	60	16	38	89
240	Quarter	Std.	45	60	18	43	93
240	Quarter	Small	45	90	18	45	97
240	Quarter	Small	45	75	25	58	*
240	Quarter	Small	45	60	34	85	99
240	Quarter	Small	25	90	54	121	*
240	Quarter	Small	25	150	39	81	98

* - Not Measured

[0110] The data in Table X along with its graphical representation in FIGS. 20 and 21 illustrate the bleaching results

possible over various operating ranges so as to determine optimal gas-pulp contact and ozone conversion levels. The data also teach how to change shaft RPM to control fill level and pulp residence time.

Example 11

[0111] To verify that the theoretical calculations presented in FIGS. 16 and 17 were representative of the actual operation of the paddle conveyor, a series of tests were made to determine pulp bridging in various paddle conveyors operated under different parameters. To conduct these tests, a 43,2 cm (17") conveyor was fitted with a paddle shaft having five different paddle spacings-- 8,9 cm, 11,9 cm, 15,0 cm, 18,3 cm and 22,9 cm (3.5", 4.7", 5.9", 7.2" and 9")-- and was then operated as shown below in Table XI. The actual pulp consolidation forces (PCF) in N/m^2 (pounds per square foot) were calculated and the minimum paddle spacing was estimated from the theoretical data and compared to the actual results.

TABLE XI

Fill (%)	RPM	PCF (PSF)	Estimated Minimum Paddle Spacing in cm (") To Avoid Bridging	Bridging observed for spacing of 8.9 (3.5	11.9 4.7	15.0 5.9	18.3 7.2	22.9 cm 9)
25	50	575 (12)	12,7 (5)	Yes	Yes	Yes	No	No
25	90	1197 (25)	17,8 (7)	Yes	Yes	Yes	Some	No
40	30	718 (15)	14,0 (5.5)	Yes	Yes	Yes	No	No
40	50	814 (17)	15,2 (6)	Yes	Yes	Yes	Some	No
40	70	1197 (25)	17,8 (7)	Yes	Yes	Yes	No	No
40	90	1676 (35)	20,3 (8)	Yes	Yes	Yes	Some	No

These data suggest that the theoretical calculations agree with the actual observations within ± 2,54 cm (± 1 inch), and that the theoretical calculations are useful for estimating minimum paddle spacing.

Example 12

[0112] To determine the relative degree of dispersion of pulp into the open spaces of the reactor at different operating conditions, the following tests were conducted. A 43,2 cm (17") 240° quarter pitch standard size 45° paddle conveyor was operated at different RPM with counterclockwise rotation. The reactor had the same fill level for each test--about

25%. A camera was mounted at one end of the shaft and took stop-action photographs while the shaft was operating at different RPM when one of the blades was at a 12 o'clock position. Image analysis was done in a controlled area in the upper left portion of the reactor, and calculations were made to determine how much pulp occupied this area, since this is representative of the relative pulp dispersing properties of the conveyor when operated at the particular shaft speed. Results are shown below in Table XII and in Figs. 23-25.

TABLE XII

Rotational Speed (RPM)	% of Rectangle Showing Pulp
20	22%
40	47%
60	58%

[0113] This illustrates the greater pulp dispersing capabilities of the paddle conveyor when operated at higher RPM. As explained above, the fill level of the reactor is reduced when higher shaft RPM are used, but this data illustrates the benefits in pulp dispersion which can be achieved at higher RPM for the same fill level.

Example 13

[0114] The paddle conveyor can achieve excellent results over a wide range of pulp feed rates. For example, ozone conversions of at least 90% and similar levels of brightness increase achieved at both 18 ODTPD and 11 ODTPD feed rates, where at 11 ODTPD the paddle rotational speed was decreased to maintain an approximately constant fill level in the reactor, as shown below in Table XIII.

TABLE XIII

Feed Rate (OPTPD)	Paddle Rotational Speed (RPM)	Fill Level (%)	Ozone Conversion (%)	Change In GEB Brightness (%)
19	60	36	93	13
11	30	40	90	12

[0115] While it is apparent that the invention herein disclosed is well calculated to fulfill the objects above stated, it will be appreciated that numerous modifications and embodiments may be devised by those skilled in the art. For example, in addition to the preferred paddle conveyors, other conveying elements such as cut and folded screw flights, ribbon mixers, elbow shaped lifting elements and wedge shaped flight elements can be used, as shown in FIGS. 26-29.

Claims

1. A bleaching apparatus for ozone bleaching of high consistency pulp particles having a range of floc sizes comprising

fluffer means (10) for reducing the floc size of the pulp particles and providing the particles with a first bulk density,

a reactor apparatus (14) having

an elongated shell (42) adapted to receive the pulp particles and an ozone containing gas, said shell defining a pulp inlet (44) and a pulp outlet (46);

means for introducing the high consistency pulp particles into the inlet (44) of the shell (42); and

rotating means (48) for radially dispersing said pulp particles substantially completely across the entire cross-section of the shell (42), while simultaneously conveying said pulp particles through the shell (42) to the outlet (46) in a plug flow-like manner, characterized in that

the rotating means (48) comprises first means for conveying the pulp introduced through the inlet (44) and having a first bulk density at a first conveying rate and second means for gradually reducing the conveying rate through the shell to a second lower conveying rate which conveys the radially disposed pulp particles

through the shell (42) to the outlet (46), whereby the density of the pulp is gradually increased by the second means to a second increased bulk density.

2. The bleaching apparatus according to claim 1, wherein the rotation means comprises a conveyor having a first section that provides the initial and reducing conveying rates and a second section that provides the second conveying rate with a dispersion index for the pulp of less than about 7.

3. The bleaching apparatus according to claim 2, wherein at least the second section of the conveyor comprises radially extending members (52) mounted in a predetermined arrangement on a rotatable shaft, and the dispersion index is maintained at all rotational speeds of said rotating means (48) under about 125 rpm.

4. The bleaching apparatus according to claim 3, wherein the members (52) in the second section are arranged around the shaft at 120° or 240° spacings in a helical quarter- or half-pitch pattern.

5. The bleaching apparatus according to claim 3, wherein said radially extending members define a rotational diameter for the conveyor and said members are paddles (52) located in both the first and second sections of the conveyor with a preselected number of the paddles (52) having a width of less than about 0.3 times the rotational diameter.

6. The bleaching apparatus according to claim 5, wherein a first portion of the preselected number of paddles (52) each has a width equal to about 0.15 times the rotational diameter and a second portion of said number each has a width greater than the paddles of the first portion, and wherein the paddles (52) of the first portion provide a conveying rate which is less than that of the paddles (52) of the second portion at the same rotational sped, with the first portion of paddles located in the second conveyor section and the second portion of the paddles located in the first conveyor section.

7. The bleaching apparatus according to claim 6, wherein each of the paddles (52) is mounted upon the shaft at an angle (θ) of between 30° and 50° with respect to the shaft centerline (58).

8. The bleaching apparatus according to claim 7, wherein the paddle angle (θ) gradually decreases along the shaft in the first conveyor section from about 45° to about 35°.

9. The bleaching apparatus according to claim 3, wherein the radially extending members are paddles which are spaced apart in the longitudinal direction to provide an unswept distance between paddles (52) of less than 0.11 times the rotational diameter.

10. The bleaching apparatus according to claim 2, wherein at least the second section of the conveyor comprises a screw flight defining a pitch of the rotating means (48), said screw flight having a plurality of portions cut out (154) from the flight to form openings therein, said cut out portions (154) being bent at a predetermined angle with respect to the shaft.

11. The bleaching apparatus according to claim 2, wherein at least the second portion of the conveyor comprises a screw flight defining a pitch of the rotating means (48), said screw flight having one or more lifting elements attached to each flight.

12. The bleaching apparatus according to claim 2, wherein at least the second section of the conveyor comprises a ribbon blade (164) mounted helically around a rotatable shaft in a predetermined pitch.

13. The bleaching apparatus according to claim 2, wherein at least the second section of the conveyor comprises an inclined ribbon (164) having infinite pitch extending from the rotatable shaft.

14. The bleaching apparatus according to claim 2, wherein the first conveyor section receives the pulp from the inlet (44) at a first bulk density and delivers the pulp to the second conveyor section at a second, increased bulk density.

15. The bleaching apparatus according to claim 14, wherein the fluffer means (10) for reducing the floc size of the pulp and providing the pulp with said first bulk density are disposed vertically above the reactor inlet (44) and communicating with the reactor shell (42) through said inlet (44) for free fall of pulp onto said first conveyor section.

16. The bleaching apparatus according to claim 15, further comprising pulp de-entrainment means (12) for separating pulp fibers from said ozone containing gas prior to removal of said gas from the bleaching apparatus, said de-entrainment means (12) including a frusto-conical wall (20) to provide an increasing cross-sectional area and being disposed between the reactor apparatus inlet (44) and said fluffer means (10) for passage of pulp therethrough into the reactor apparatus inlet (44).

17. The bleaching apparatus according to claim 16, further comprising:

a receiving tank (18) and;

means for quenching (16) the ozone bleaching reaction on said pulp by adding water to the pulp and lowering the consistency of the pulp, said quenching means (16) disposed vertically below the reactor apparatus outlet (46) to receive bleached pulp therefrom and including a plurality of downwardly angled nozzles (36) for forcing the pulp into the receiving tank (18) by a water spray.

18. The bleaching apparatus according to claim 1, wherein the ozone containing gas is adapted to flow cocurrently to the movement of pulp and is supplied into the reactor shell (42) through multiple ports therein.

19. A method for ozone bleaching of high consistency pulp particles, comprising:

fluffing high consistency pulp particles for reducing the floc size of the pulp particles providing pulp particles with a first bulk density,

introducing high consistency pulp particles and an ozone containing gas into a reaction zone, <u>characterized in</u>

initially conveying the pulp particles at a first conveying rate followed by gradually reducing the conveying rate of the pulp to a second lower conveying rate; while dispersing and conveying the pulp particles substantially completely throughout the reaction zone in a plug flow-like manner at the second conveying rate, whereby the pulp density is increased from a first bulk density at the first conveying rate to a second increased bulk density at the second conveying rate.

20. The method according to claim 19, wherein the second conveying rate is a dispersion index for the pulp particles of about 7 or less thus exposing substantially all surfaces of the pulp particles to the ozone containing gas for reaction therewith.

21. The method according to claim 19, further comprising:

removing the gas flow from the reaction zone with entrained pulp particles at a first flow rate;

reducing the flow rate of the removed gas to a rate where the entrained pulp particles become de-entrained and

returning the de-entrained pulp particles to the reaction zone.

22. The method according to claim 19, further comprising;

removing bleached pulp from the reaction zone;

spraying the bleached pulp with water to lower the consistency of the pulp particles and quench the bleaching reaction; and

forcing the pulp into a receiving means (18) by angling the water spray towards said receiving means (18).

23. The method according to claim 19, which further comprises conveying the pulp particles with a conveying means that include radially extending members mounted in a predetermined arrangement on a rotatable shaft (48), so that the dispersion index remains at less than about 7 at all rotational speeds of the shaft under about 125 rpm.

24. The method according to claim 23 which further comprises configuring a preselected number of the radially extending members to have a width of less than about 0.3 times the rotational diameter of the conveying means.

25. The method according to claim 23 which further comprises configuring the radially extending members to provide an unswept distance between said members of less than 0.11 times the rotational diameter of the conveying means.

Patentansprüche

1. Bleichvorrichtung zum Ozonbleichen von Teilchen eines Zellstoffs mit hoher Stoffdichte mit einem Bereich von Flockengrößen, die umfaßt

   eine Flockungseinrichtung (10), um die Flockengröße der Zellstoffteilchen zu vermindern und die Teilchen mit einer ersten Rohdichte bereitzustellen,

   eine Reaktorvorrichtung (14) mit

   einem langgestreckten Gehäuse (42) zur Aufnahme der Zellstoffteilchen und eines ozonhaltigen Gases, wobei das Gehäuse einen Zellstoffeinlaß (44) und einen Zellstoffauslaß (46) aufweist;

   eine Einrichtung, um die Teilchen des Zellstoffs mit hoher Stoffdichte dem Einlaß (44) des Gehäuses (42) zuzuführen; und

   eine Rotationseinrichtung (48) zum radialen Dispergieren der Zellstoffteilchen im wesentlichen vollständig über den gesamten Querschnitt des Gehäuses (42), während gleichzeitig die Zellstoffteilchen durch das Gehäuse (42) zu dem Auslaß (46) in einer pfropfenartigen Strömung gefördert werden, **dadurch gekennzeichnet,** daß

   die Rotationseinrichtung (48) eine erste Einrichtung zum Fördern des über den Einlaß (44) eingeführten Zellstoffs mit einer ersten Rohdichte bei einer ersten Fördergeschwindigkeit und eine zweite Einrichtung zur allmählichen Verminderung der Fördergeschwindigkeit durch das Gehäuse auf eine zweite niedrigere Fördergeschwindigkeit umfassen, die die radial dispergierten Zellstoffteilchen durch das Gehäuse (42) zu dem Auslaß (46) fördern, wobei die Rohdichte durch die zweite Einrichtung allmählich auf eine zweite erhöhte Rohdichte vergrößert wird.

2. Bleichvorrichtung nach Anspruch 1, wobei die Rotationseinrichtung einen Förderer mit einem ersten Abschnitt, der die anfänglichen und verminderten Fördergeschwindigkeiten gewährleistet, und einem zweiten Abschnitt, der die zweite Fördergeschwindigkeit mit einem Dispersionsindex für den Zellstoff von weniger als etwa 7 gewährleistet, umfasst.

3. Bleichvorrichtung nach Anspruch 2, wobei wenigstens der zweite Abschnitt des Förderers sich radial erstreckende Teile (52) umfaßt, die in einer vorbestimmten Anordnung auf einer rotierbaren Welle angebracht sind, und wobei bei allen Rotationsgeschwindigkeiten der Rotationseinrichtung (48) unter etwa 125 U/min der Dispersionsindex eingehalten wird.

4. Bleichvorrichtung nach Anspruch 3, wobei die Teile (52) in dem zweiten Abschnitt um die Welle mit Abständen von 120° oder 240° in einem Muster mit einer helikalen Viertel- oder Halbschraubensteigung angeordnet sind.

5. Bleichvorrichtung nach Anspruch 3, wobei die sich radial erstreckenden Teile einen Rotationsdurchmesser für den Förderer definieren und wobei die Teile Schaufeln (52) sind, die sowohl in dem ersten wie auch in dem zweiten Abschnitt des Förderers in einer vorgewählten Zahl von Schaufeln (52) mit einer Breite von weniger als dem etwa 0,3 fachen des Rotationsdurchmessers angeordnet sind.

6. Bleichvorrichtung nach Anspruch 5, wobei ein erster Teil der vorgewählten Zahl von Schaufeln (52) jeweils eine Breite hat, die dem etwa 0,15 fachen des Rotationsdurchmessers entspricht, und ein zweiter Teil der Zahl eine Breite aufweist, die größer ist als die der Schaufeln des ersten Teils, und wobei die Schaufeln (52) des ersten Teils eine Fördergeschwindigkeit gewährleisten, die bei der gleichen Rotationsgeschwindigkeit geringer ist als die der Schaufeln (52) des zweiten Teils, wobei der erste Teil der Schaufeln in dem zweiten Förderabschnitt angeordnet ist und der zweite Teil der Schaufeln in dem ersten Förderabschnitt angeordnet ist.

7. Bleichvorrichtung nach Anspruch 6, wobei jede der Schaufeln (52) auf der Welle in einem Winkel (θ) von zwischen

30° und 50° bezüglich der Wellenmittelachse (58) angeordnet ist.

8. Bleichvorrichtung nach Anspruch 7, wobei der Schaufelwinkel (θ) entlang der Welle in dem ersten Förderabschnitt allmählich von etwa 45° auf etwa 35° abnimmt.

9. Bleichvorrichtung nach Anspruch 3, wobei die sich radial erstreckenden Teile Schaufeln sind, die voneinander in longitudinaler Richtung beabstandet sind, so daß ein unbestrichener Abstand zwischen den Schaufeln (52) von weniger als dem 0,11 fachen des Rotationsdurchmessers gebildet wird.

10. Bleichvorrichtung nach Anspruch 2, wobei wenigstens der zweite Abschnitt des Förderers einen Schraubengang umfaßt, der eine Schraubensteigung der Rotationseinrichtung (48) definiert, wobei der Schraubengang eine Vielzahl von aus dem Gang ausgeschnittenen Segmenten (154) aufweist, um darin Öffnungen zu bilden, wobei die ausgeschnittenen Segmente (154) in bezug auf die Welle mit einem vorbestimmten Winkel abgebogen sind.

11. Bleichvorrichtung nach Anspruch 2, wobei wenigstens der zweite Abschnitt des Förderers einen Schraubengang umfaßt, der eine Schraubensteigung der Rotationseinrichtung (48) definiert, wobei dieser Schraubengang eines oder mehrere Hebeelemente aufweist, die an jedem Gang befestigt sind.

12. Bleichvorrichtung nach Anspruch 2, wobei wenigstens der zweite Abschnitt des Förderers eine Bandschaufel (164) umfaßt, die um eine rotierbare Welle herum schraubenartig mit einer festgelegten Schraubensteigung montiert ist.

13. Bleichvorrichtung nach Anspruch 2, wobei wenigstens der zweite Abschnitt des Förderers ein Schrägband (164) umfaßt, das eine stufenlose Schraubensteigung aufweist, das sich von der rotierbaren Welle wegerstreckt.

14. Bleichvorrichtung nach Anspruch 2, wobei der erste Förderabschnitt den Zellstoff von dem Einlaß (44) mit einer ersten Rohdichte erhält und den Zellstoff an den zweiten Förderabschnitt mit einer zweiten vergrößerten Rohdichte übergibt.

15. Bleichvorrichtung nach Anspruch 14, wobei die Flockungseinrichtung (10) zum Vermindern der Flockengröße des Zellstoffs und zum Bereitstellen des Zellstoffs mit der ersten Rohdichte vertikal über dem Reaktoreinlaß (44) angeordnet ist und mit dem Reaktorgehäuse (42) durch den Einlaß (44) für den freien Fall von Zellstoff auf den ersten Förderabschnitt verbunden ist.

16. Bleichvorrichtung nach Anspruch 15, die ferner eine Zellstoffrückhalteeinrichtung (12) umfaßt, um die Zellstofffasern von dem ozonhaltigen Gas vor dem Entfernen dieses Gases aus der Bleichvorrichtung abzutrennen, wobei die Rückhalteeinrichtung (12) eine Kegelstumpfwand (20) enthält, so daß eine sich vergrößernde Querschnittsfläche erhalten wird, die zwischen dem Reaktorvorrichtungseinlaß (44) und der Flockungseinrichtung (10) zum Durchgang von Zellstoff in den Reaktorvorrichtungseinlaß (44) angeordnet ist.

17. Bleichvorrichtung nach Anspruch 16, die ferner umfaßt

einen Aufnahmebehälter (18); und

eine Einrichtung zum Quenchen (16) der Ozonbleichreaktion des Zellstoffs, indem Wasser zu dem Zellstoff hinzugefügt wird und die Stoffdichte des Zellstoffs verringert wird, wobei die Quencheinrichtung (16) vertikal unter dem Reaktorvorrichtungsauslaß (46) angeordnet ist, um daraus den gebleichten Zellstoff aufzunehmen, und wobei sie eine Vielzahl von abwärtsgewinkelten Düsen (36) aufweist, um den Zellstoff mit einem Wasserstrahl in den Aufnahmebehälter (18) zu drücken.

18. Bleichvorrichtung nach Anspruch 1, wobei das ozonhaltige Gas so vorgesehen ist, daß es im Gleichstrom zu der Bewegung des Zellstoffs strömt und dem Reaktorgehäuse (42) durch viele darin ausgebildete Öffnungen zugeführt wird.

19. Verfahren zum Ozonbleichen von Teilchen eines Zellstoffs mit hoher Stoffdichte, das umfaßt:

die Flockenbildung der Teilchen des Zellstoffs mit hoher Stoffdichte, um die Flockengröße der Zellstoffteilchen zu vermindern, um Zellstoffteilchen mit einer ersten Rohdichte bereitzustellen,

das Einführen der Teilchen des Zellstoffs mit hoher Stoffdichte und eines ozonhaltigen Gases in eine Reaktionszone, **dadurch gekennzeichnet,** daß

die Zellstoffteilchen anfänglich mit einer ersten Fördergeschwindigkeit gefördert werden, woran sich eine allmähliche Verminderung der Fördergeschwindigkeit des Zellstoffs auf eine zweite niedrigere Fördergeschwindigkeit anschließt; wobei die Zellstoffteilchen im wesentlichen vollständig dispergiert und in einer pfropfenartigen Strömung bei der zweiten Fördergeschwindigkeit durch die Reaktionszone gefördert werden, wobei der Zellstoff von einer ersten Rohdichte bei einer ersten Fördergeschwindigkeit auf eine zweite erhöhte Rohdichte bei einer zweiten Fördergeschwindigkeit gebracht wird.

20. Verfahren nach Anspruch 19, wobei die zweite Fördergeschwindigkeit einen Dispersionsindex für die Zellstoffteilchen von etwa 7 oder weniger gewährleistet, so daß im wesentlichen alle Oberflächen der Zellstoffteilchen dem ozonhaltigen Gas zur Reaktion ausgesetzt sind.

21. Verfahren nach Anspruch 19, das ferner umfaßt:

Entfernen des Gasstroms aus der Reaktionszone mit mitgerissenen Zellstoffteilchen bei einer ersten Strömungsgeschwindigkeit;

Vermindern der Strömungsgeschwindigkeit des entfernten Gases auf eine Geschwindigkeit, bei der die mitgerissenen Zellstoffteilchen zurückgehalten werden und

Zurückführen der zurückgehaltenen Zellstoffteilchen in die Reaktionszone.

22. Verfahren nach Anspruch 19, das ferner umfaßt;

das Entfernen des gebleichten Zellstoffs aus der Reaktionszone;

das Besprühen des gebleichten Zellstoffs mit Wasser, um die Stoffdichte der Zellstoffteilchen zu vermindern und die Bleichreaktion zu quenchen; und

Drücken des Zellstoffs in eine Aufnahmeeinrichtung (18) durch Abwinkeln des Wassersprays in Richtung der Aufnahmeeinrichtung (18).

23. Verfahren nach Anspruch 19, das ferner das Fördern der Zellstoffteilchen mit einer Fördereinrichtung umfaßt, die sich radial erstreckende Teile enthält, die in einer vorgegebenen Weise auf einer rotierbaren Welle (48) befestigt sind, so daß der Dispersionsindex bei allen Rotationsgeschwindigkeiten der Welle unter etwa 125 U/min unter etwa 7 bleibt.

24. Verfahren nach Anspruch 23, das ferner das Konfigurieren einer vorgewählten Anzahl von sich radial erstreckenden Teilen umfaßt, so daß sie eine Breite von weniger als dem etwa 0,3fachen des Rotationsdurchmessers der Fördereinrichtung aufweisen.

25. Verfahren nach Anspruch 23, das ferner das Konfigurieren der sich radial erstreckenden Teilen umfaßt, so daß ein unbestrichener Abstand zwischen den Teilen von weniger als dem 0,llfachen des Rotationsdurchmessers der Fördereinrichtung erhalten wird.

Revendications

1. Dispositif de blanchiment pour blanchiment à l'ozone de particules de pâte à consistance élevée ayant une plage de dimensions de floc comportant :

des moyens de peluchage (10) pour réduire la dimension de floc des particules de pâte et donner aux particules une première densité,
un dispositif (14) formant réacteur ayant
une enveloppe allongée (42) adaptée pour recevoir les particules de pâte et un gaz contenant de l'ozone, ladite enveloppe définissant une entrée de pâte (44) et une sortie de pâte (46),

des moyens pour introduire les particules de pâte à consistance élevée dans l'entrée (44) de l'enveloppe (42), et

des moyens rotatifs (48) pour disperser radialement lesdites particules de pâte pratiquement entièrement à travers toute la section transversale de l'enveloppe (42), tout en transportant simultanément lesdites particules de pâte à travers l'enveloppe (420) vers la sortie (46) d'une manière analogue à un écoulement idéal, caractérisé en ce que

les moyens rotatifs (48) comportent des premiers moyens pour transporter la pâte introduite à travers l'entrée (44) et ayant une première densité à une première vitesse de transport et des seconds moyens pour réduire graduellement la vitesse de transport à travers l'enveloppe jusqu'à une seconde vitesse de transport plus faible qui transporte les particules de pâte disposées radialement à travers l'enveloppe (42) vers la sortie (46), de sorte que la densité de la pâte est graduellement augmentée par les seconds moyens jusqu'à une seconde densité accrue.

2. Dispositif de blanchiment selon la revendication 1, dans lequel les moyens de rotation comportent un convoyeur ayant un premier tronçon qui fournit la vitesse de transport initial et réduit la vitesse de transport et un second tronçon qui fournit la seconde vitesse de transport avec un indice de dispersion de la pâte inférieur à environ 7.

3. Dispositif de blanchiment selon la revendication 2, dans lequel au moins le second tronçon du convoyeur comporte des éléments s'étendant radialement (52) montés selon un agencement prédéterminé sur un arbre rotatif, et l'indice de dispersion est maintenu pour toutes les vitesses de rotation desdits moyens rotatifs (48) situées en dessous d'environ 125 tours par minute.

4. Dispositif de blanchiment selon la revendication 3, dans lequel les éléments (52) du second tronçon sont agencés autour de l'arbre selon des écartements de 120°C ou 240°C dans un motif hélicoïdal quart de pas ou demi-pas.

5. Dispositif de blanchiment selon la revendication 3, dans lequel lesdits éléments s'étendant radialement définissent un diamètre de rotation pour le convoyeur et lesdits éléments sont des pales (52) positionnées dans les deux premier et second tronçons du convoyeur, un nombre sélectionné de pales (52) ayant une largeur plus petite qu'environ 0,3 fois le diamètre de rotation.

6. Dispositif de blanchiment selon la revendication 5, dans lequel chacune d'une première partie du nombre présélectionné de pales (52) a une largeur égale à environ 0,15 fois le diamètre de rotation et chacune d'une seconde partie dudit nombre a une largeur plus grande que les pales de la première partie, et dans lequel les pales (52) de la première partie fournissent une vitesse de transport qui est plus petite que celle des pales (52) de la seconde partie à la même vitesse de rotation, la première partie de pale étant positionnée dans le second tronçon de convoyeur et la seconde partie de pale étant positionnée dans le premier tronçon de convoyeur.

7. Dispositif de blanchiment selon la revendication 6, dans lequel chacune des pales (52) est montée sur l'arbre en faisant un angle (θ) compris entre 30 et 50°C par rapport à l'axe central de l'arbre (58).

8. Dispositif de blanchiment selon la revendication 7, dans lequel l'angle de pale (θ) diminue graduellement le long de l'arbre dans le premier tronçon de convoyeur depuis environ 45°C jusqu'à environ 35°C.

9. Dispositif de blanchiment selon la revendication 3, dans lequel les éléments s'étendant radialement sont des pales qui sont espacées dans la direction longitudinale pour fournir une distance non-balayée entre les pales (52) plus petite que 0,11 fois le diamètre de rotation.

10. Dispositif de blanchiment selon la revendication 2, dans lequel au moins le second tronçon du convoyeur comporte un voile hélicoïdal définissant le pas des moyens rotatifs (48), ledit voile hélicoïdal ayant une pluralité de parties découpées (154) à partir du voile pour former des ouvertures dans celui-ci, lesdites parties découpées (154) étant pliées selon un angle prédéterminé par rapport à l'arbre.

11. Dispositif de blanchiment selon la revendication 2, dans lequel au moins la seconde partie du convoyeur comporta un voile hélicoïdal définissant le pas des moyens rotatifs (48), ledit voile hélicoïdal ayant un ou plusieurs éléments de levage fixés sur chaque voile.

12. Dispositif de blanchiment selon la revendication 2, dans lequel au moins le second tronçon du convoyeur est constitué d'une aube en ruban (164) montée hélicoïdalement autour d'un arbre rotatif selon un pas prédéterminé.

13. Dispositif de blanchiment selon la revendication 2, dans lequel au moins le second tronçon du convoyeur comporte un ruban incliné (164) ayant un pas infini s'étendant à partir de l'arbre rotatif.

14. Dispositif de blanchiment selon la revendication 2, dans lequel le premier tronçon de convoyeur reçoit la pâte provenant de l'entrée (4) ayant une première densité et délivre la pâte vers le second tronçon de convoyeur à une seconde densité accrue.

15. Dispositif de blanchiment selon la revendication 14, dans lequel les moyens de peluchage (10) destinés à réduire la dimension de floc de la pâte et à donner à la pâte ladite première densité sont disposés verticalement au-dessus de l'entrée d'un réacteur (44) et communiquent avec l'enveloppe de réacteur (42) à travers ladite entrée (44) pour la chute libre de la pâte sur ledit premier tronçon de convoyeur.

16. Dispositif de blanchiment selon la revendication 15, comportant en outre des moyens de dégazage de la pâté (12) pour séparer les fibres de pâte dudit gaz contenant de l'ozone avant d'enlever ledit gaz du dispositif de blanchiment, lesdits moyens de dégazage (12) comportant une paroi tronconique (20) pour fournir une surface croissante en coupe et étant disposés entre l'entrée du dispositif formant réacteur (44) et lesdits moyens de peluchage (10) pour le passage traversant de la pâte jusqu'à l'entrée du dispositif formant réacteur (44).

17. Dispositif de blanchiment selon la revendication 16, comportant en outre :

un réservoir de réception (18), et
des moyens pour éteindre (16) la réaction de blanchiment à l'ozone sur ladite pâte en ajoutant de l'eau à ladite pâte et en abaissant la consistance de la pâte, lesdits moyens d'extinction (16) étant disposés verticalement en dessous de la sortie du dispositif formant réacteur (46) pour recevoir la pâte blanchie provenant de celui-ci et comportant une pluralité de buses inclinées vers le bas (36) pour pousser la pâte située à l'intérieur du réservoir de réception (18) par une pulvérisation d'eau.

18. Dispositif de blanchiment selon la revendication 1, dans lequel le gaz contenant de l'ozone est adapté pour s'écouler conjointement au déplacement de la pâte et est envoyé dans l'enveloppe de réacteur (42) à travers de multiples orifices agencés dans celle-ci.

19. Procédé pour blanchir à l'ozone des particules de pâte à consistance élevée, consistant à :

pelucher des particules de pâte à consistance élevée pour réduire la dimension de floc des particules de pâte en fournissant des particules de pâte ayant une première densité,
introduire des particules de pâte à consistance élevée et un gaz contenant de l'ozone à l'intérieur d'une zone de réaction, caractérise en ce qu'il consiste en outre :
initialement à transporter des particules de pâte à une première vitesse de transport, ce qui est suivi par une réduction graduelle de la vitesse de transport de la pâte jusqu'à une seconde vitesse de transport plus faible, tout en dispersant et transportant les particules de pâte sensiblement entièrement à travers la zone de réaction d'une manière analogue à un écoulement idéal à la seconde vitesse de transport, de sorte que la densité de la pâte est augmentée d'une première densité au niveau de la première vitesse de transport à une seconde densité accrue au niveau de la seconde vitesse de transport.

20. Procédé selon la revendication 19, dans lequel la seconde vitesse de transport est un indice de dispersion des particules de pâte d'environ 7 ou plus petit en exposant ainsi sensiblement toutes les surfaces des particules de pâte au gaz contenant de l'ozone pour réaction avec ce-lui-ci.

21. Procédé selon la revendication 19, comportant en outre les étapes consistant à :

supprimer l'écoulement de gaz depuis la zone de réaction avec des particules de pâte entraînées à un premier débit,
réduire le débit du gaz enlevé à un débit où les particules de pâte entraînées deviennent séparées et ramener les particules de pâte séparées à la zone de réaction.

22. Procédé selon la revendication 19, comportant en outre les étapes consistant à :

enlever la pâte blanchie à partir de la zone de réaction,

pulvériser la pâte blanchie à l'aide d'eau pour abaisser la consistance des particules de pâte et éteindre la réaction de blanchiment, et

pousser la pâte dans des moyens de réception (18) en inclinant la pulvérisation d eau en direction desdits moyens de réception (18).

23. Procédé selon la revendication 19, qui consiste en outre à transporter des particules de pâte à l'aide de moyens de transport qui comportent des éléments s'étendant radialement montés selon un agencement prédéterminé sur un arbre rotatif (48), de sorte que l'indice de dispersion reste en dessous d'environ 7 à toutes les vitesses de rotation de l'arbre situées en dessous d'environ 125 tours par minute.

24. Procédé selon la revendication 23, qui consiste en outre à configurer un nombre présélectionné d'éléments s'étendant radialement pour qu'ils aient une largeur inférieure à environ 0,3 fois le diamètre de rotation des moyens de transport.

25. Procédé selon la revendication 23, qui consiste en outre à configurer les éléments s'étendant radialement pour fournir une distance non-balayée entre lesdits éléments plus petite que 0,11 fois le diamètre de rotation des moyens de transport.

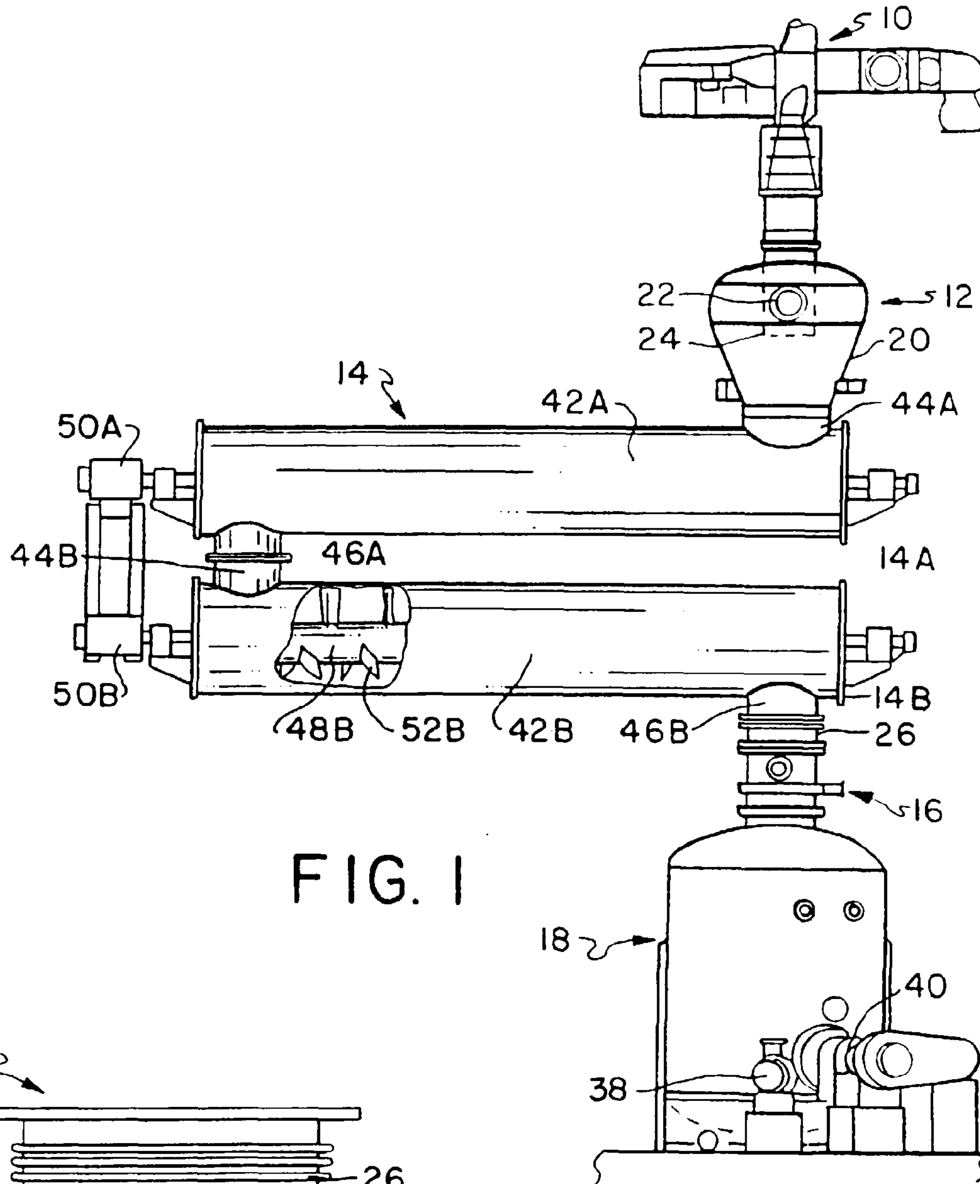

10
12
22
24
20
14
42A
44A
50A
44B
46A
14A
50B
14B
48B
52B
42B
46B
26
16
18
40
38

FIG. 1

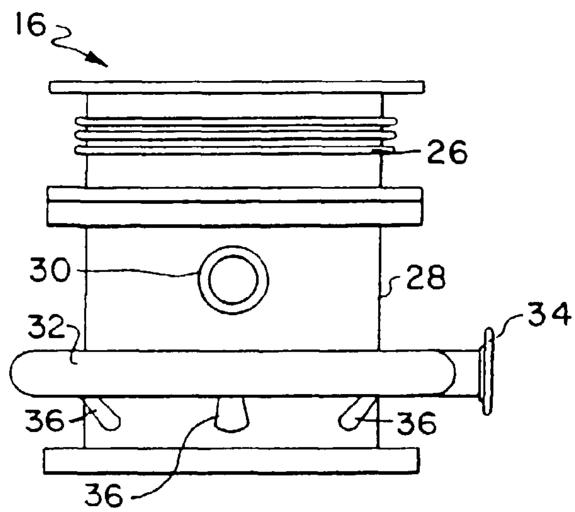

16
26
30
28
32
34
36
36
36

FIG. 2

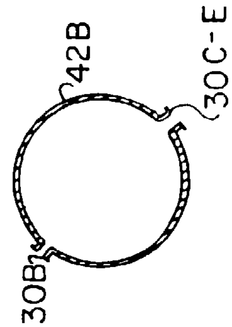


FIG.4

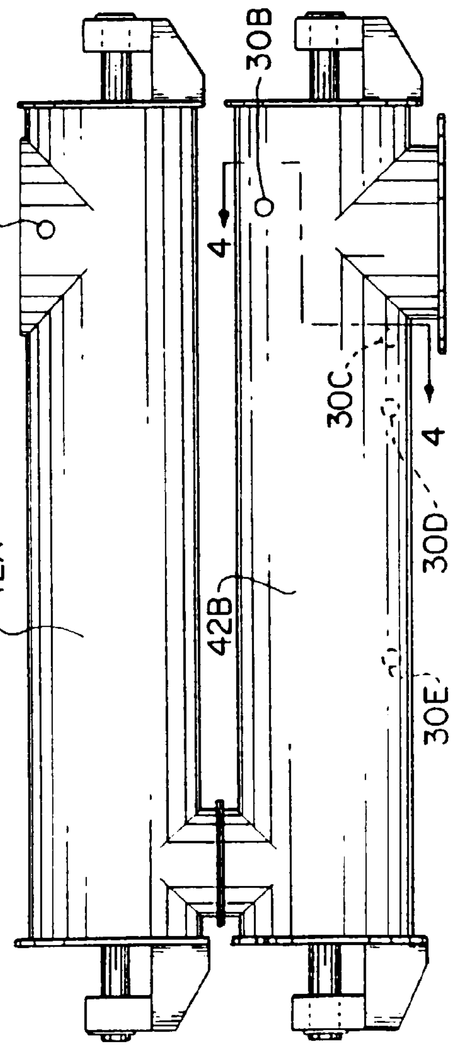


FIG. 3

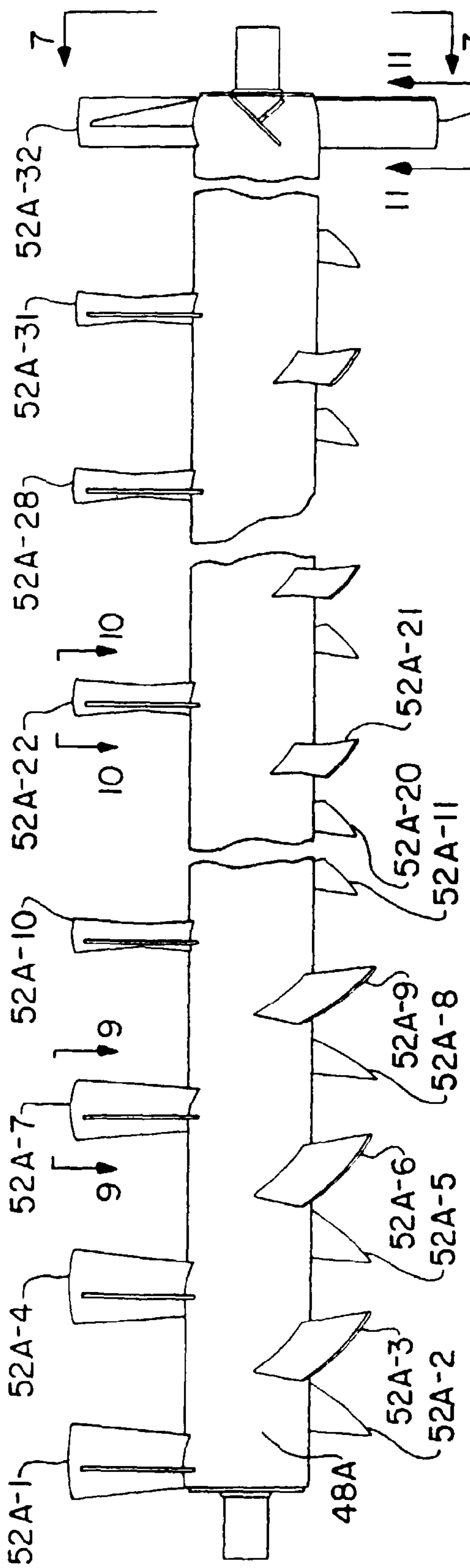

52A-1
48A
52A-2
52A-3
52A-4
52A-5
52A-6
52A-7
9
52A-8
52A-9
52A-10
52A-11
52A-20
52A-21
52A-22
10
52A-28
52A-31
52A-32
11
7

FIG. 5

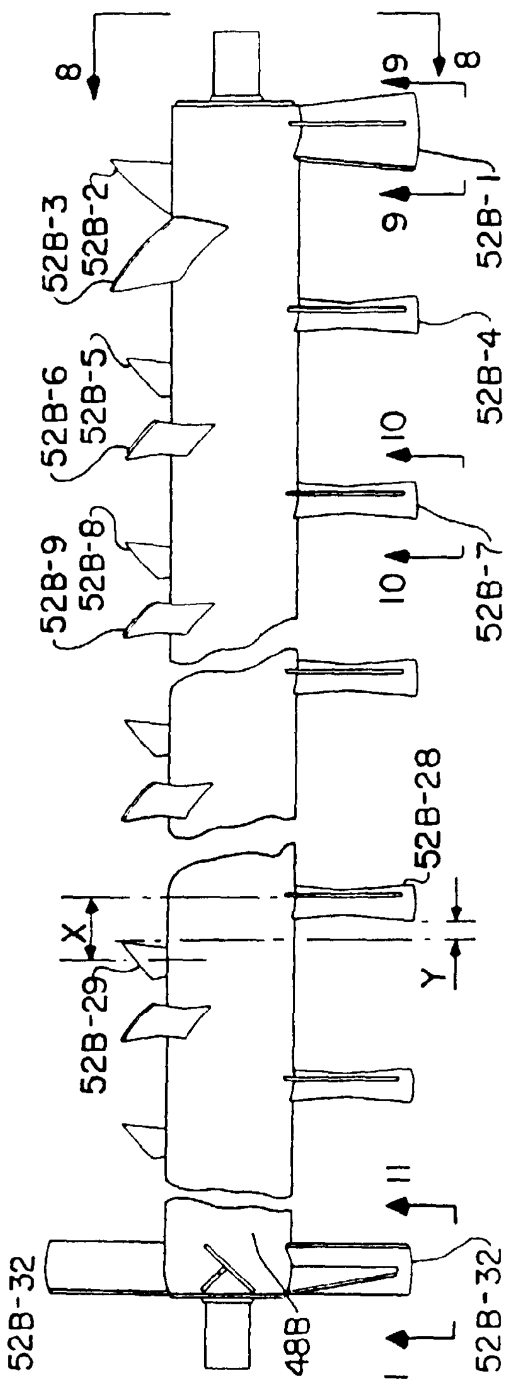

8
9
52B-1
52B-2
52B-3
52B-4
52B-5
52B-6
52B-7
52B-8
52B-9
10
52B-28
52B-29
X
Y
52B-32
48B
11

FIG. 6

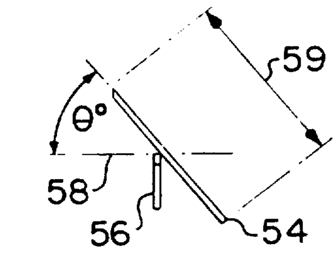


FIG. 9

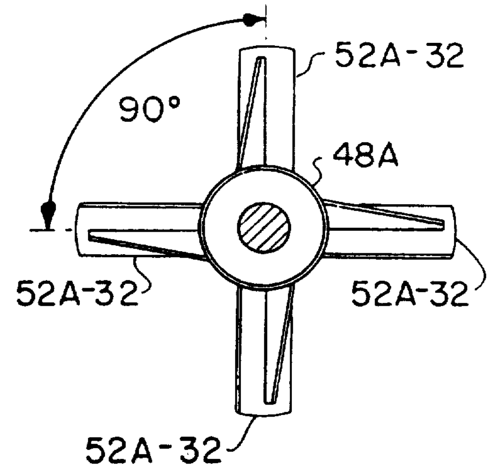


FIG. 7

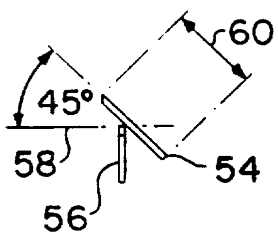


FIG. 10

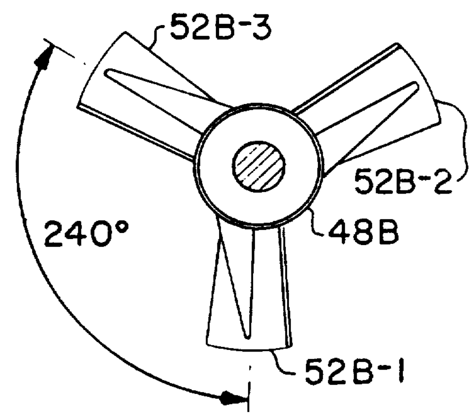


FIG. 8

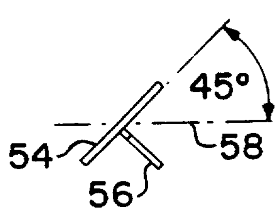


FIG. 11

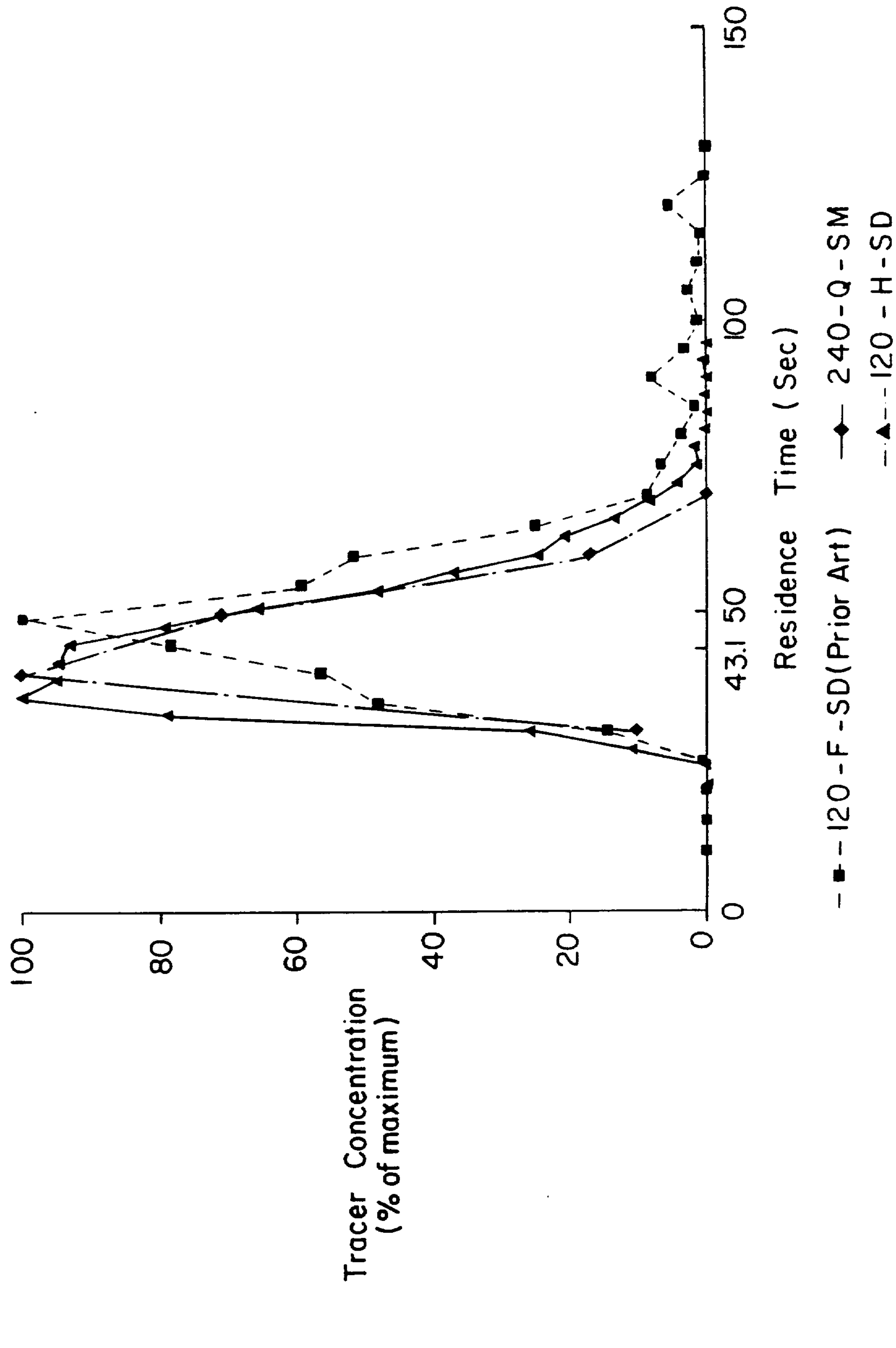
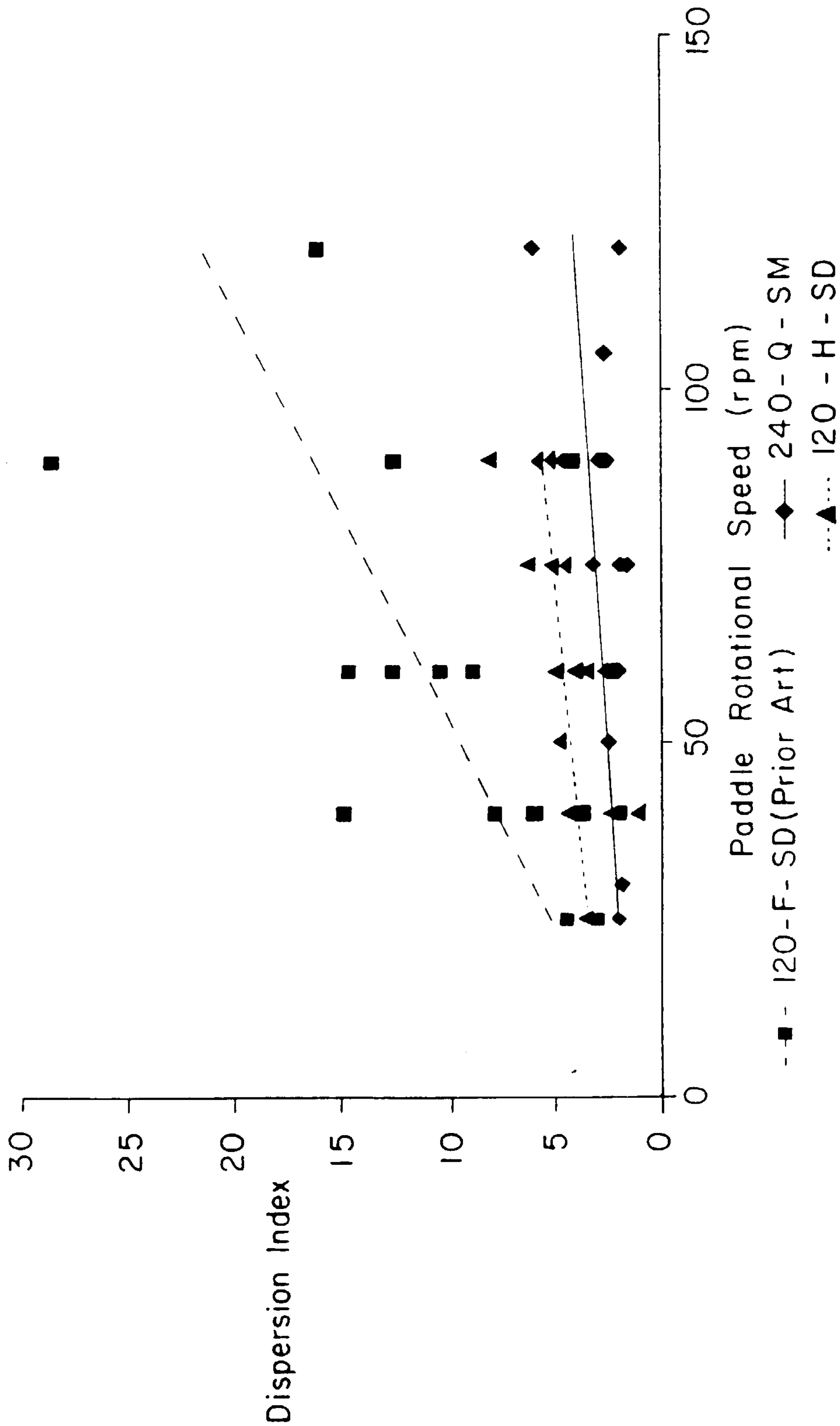

Tracer Concentration
(% of maximum)
100
80
60
40
20
0
0
43.1 50
100
150
Residence Time (Sec)
120-F-SD(Prior Art)
240-Q-SM
120-H-SD

FIG. 12



Dispersion Index
30
25
20
15
10
5
0
0
50
100
150
Paddle Rotational Speed (rpm)
120-F-SD(Prior Art)
240-Q-SM
120-H-SD

FIG. 13

FIG. 14A PRIOR ART

FIG. 14B PRIOR ART

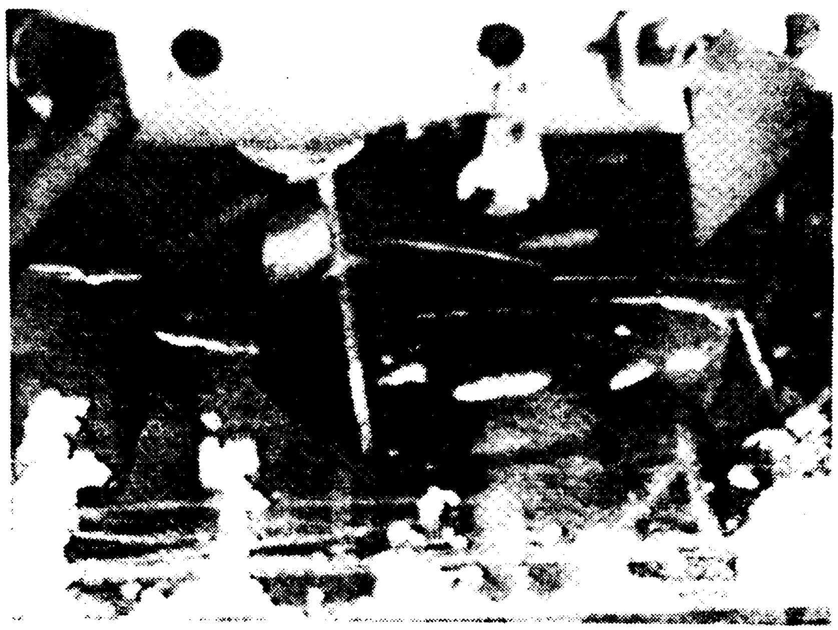


FIG. 15A

FIG. 15B

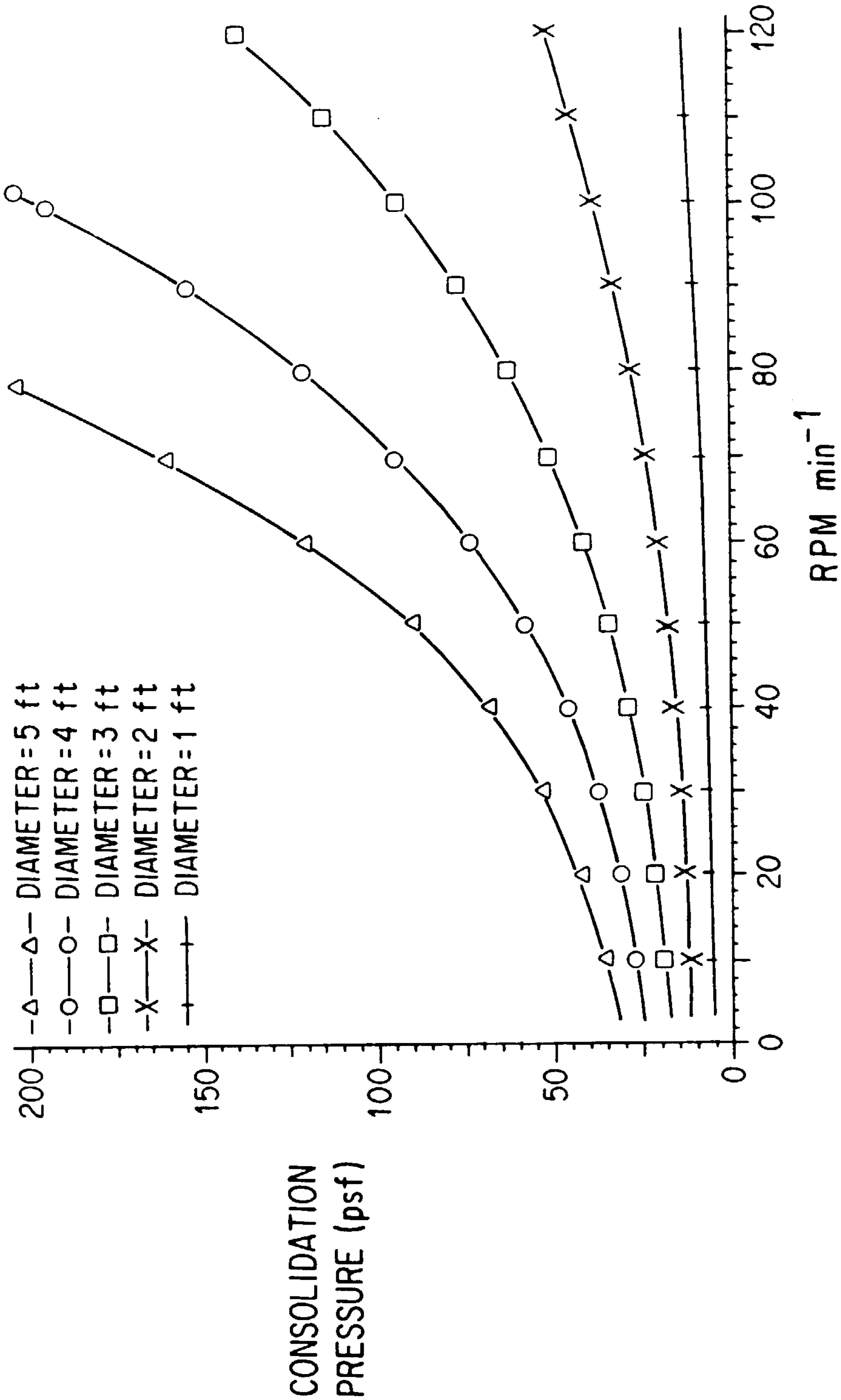

DIAMETER = 5 ft
DIAMETER = 4 ft
DIAMETER = 3 ft
DIAMETER = 2 ft
DIAMETER = 1 ft
CONSOLIDATION PRESSURE (psf)
0
50
100
150
200
RPM min^{-1}
0
20
40
60
80
100
120

FIG. 16

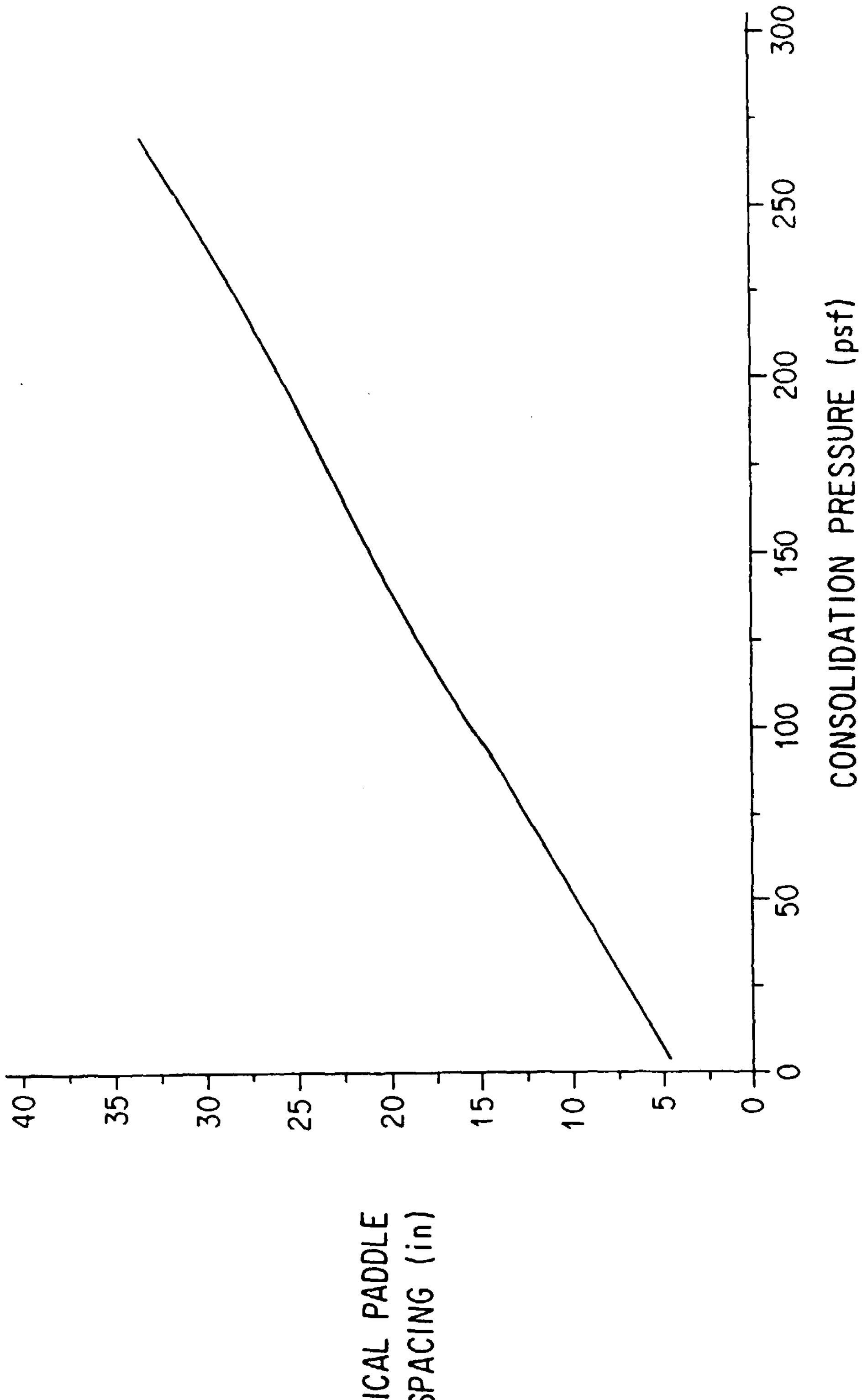

CRITICAL PADDLE SPACING (in)
0
5
10
15
20
25
30
35
40
CONSOLIDATION PRESSURE (psf)
0
50
100
150
200
250
300

FIG. 17

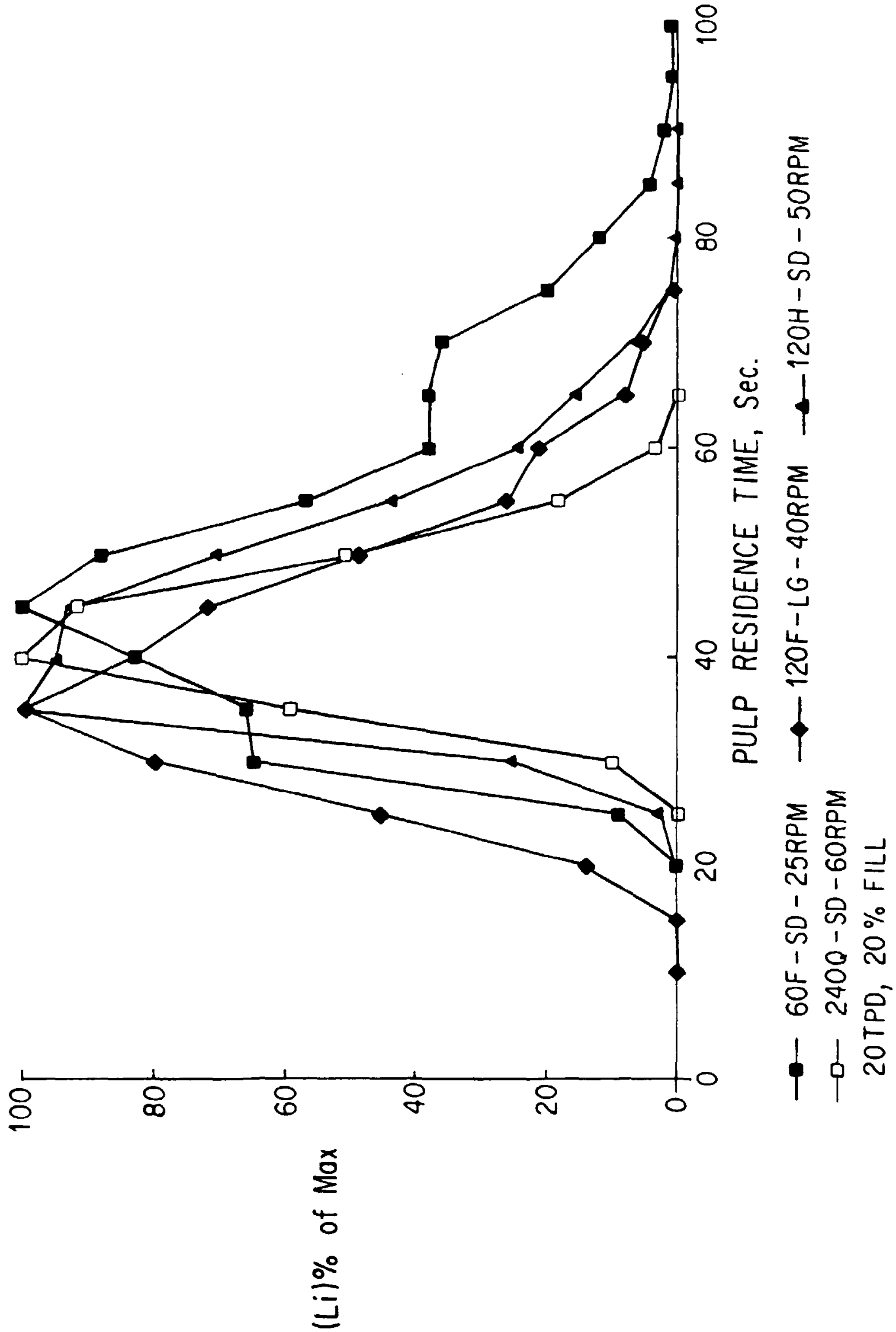

(Li)% of Max
0
20
40
60
80
100
PULP RESIDENCE TIME, Sec.
60F - SD - 25RPM
240Q - SD - 60RPM
20TPD, 20% FILL
120F - LG - 40RPM
120H - SD - 50RPM

FIG. 18

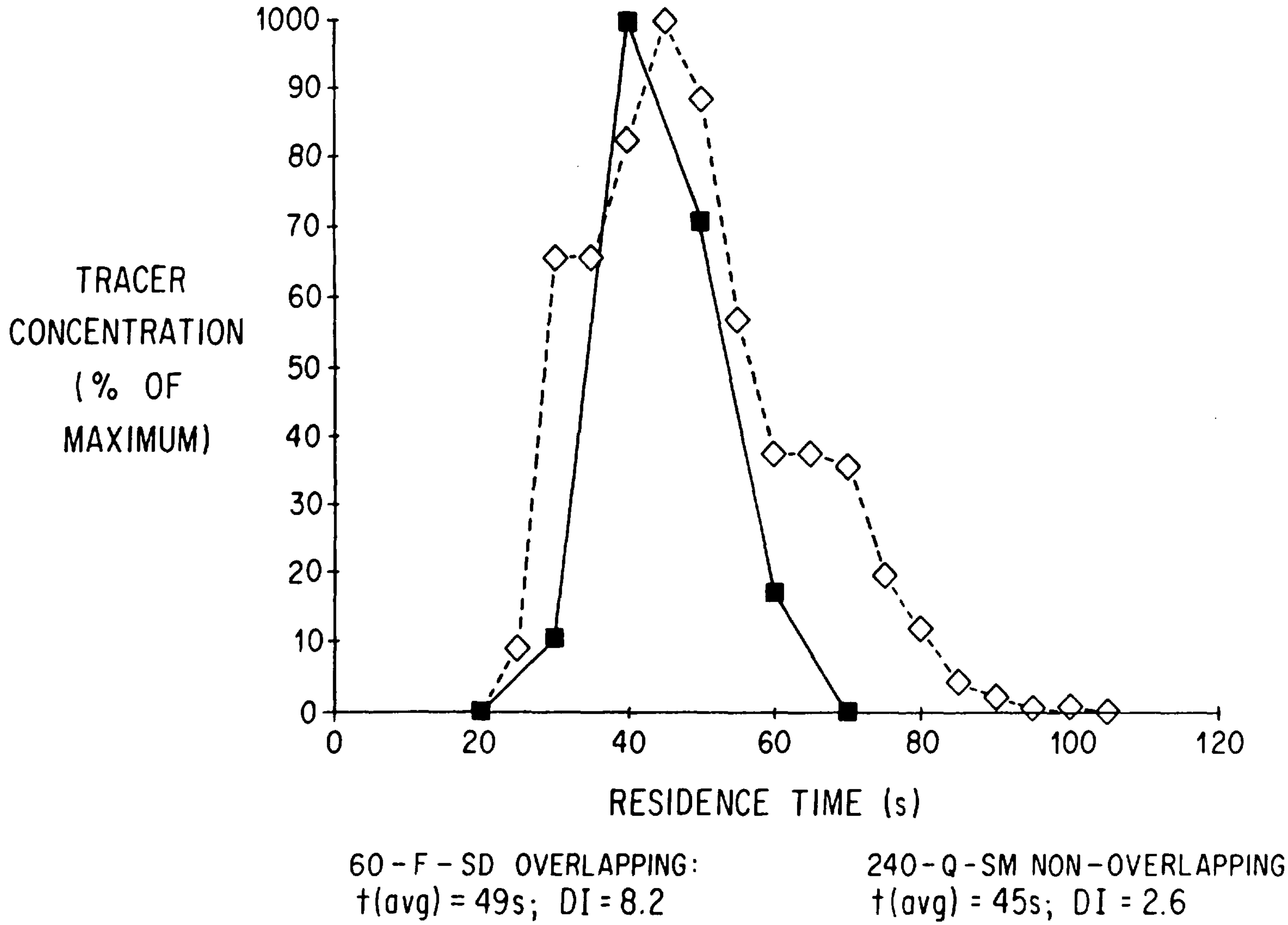

TRACER
CONCENTRATION
(% OF
MAXIMUM)
1000
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
RESIDENCE TIME (s)
60 - F - SD OVERLAPPING:
t(avg) = 49s; DI = 8.2
240 - Q - SM NON - OVERLAPPING
t(avg) = 45s; DI = 2.6

FIG. 19

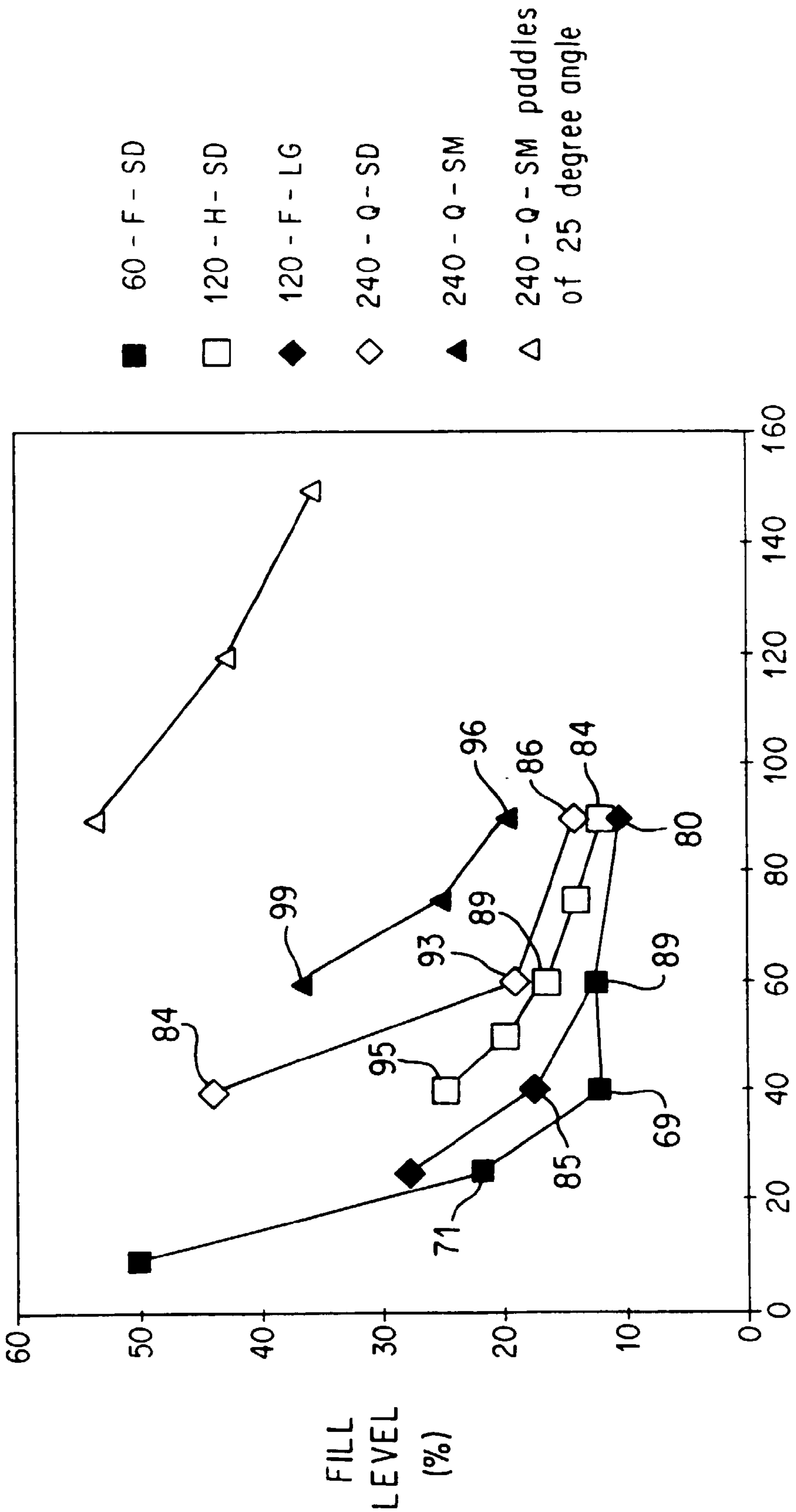

60 - F - SD
120 - H - SD
120 - F - LG
240 - Q - SD
240 - Q - SM
240 - Q - SM paddles of 25 degree angle
FILL LEVEL (%)
0
10
20
30
40
50
60
SHAFT SPEED (rpm)
0
20
40
60
80
100
120
140
160
71
69
85
89
95
84
93
89
99
96
86
84
80

FIG. 20

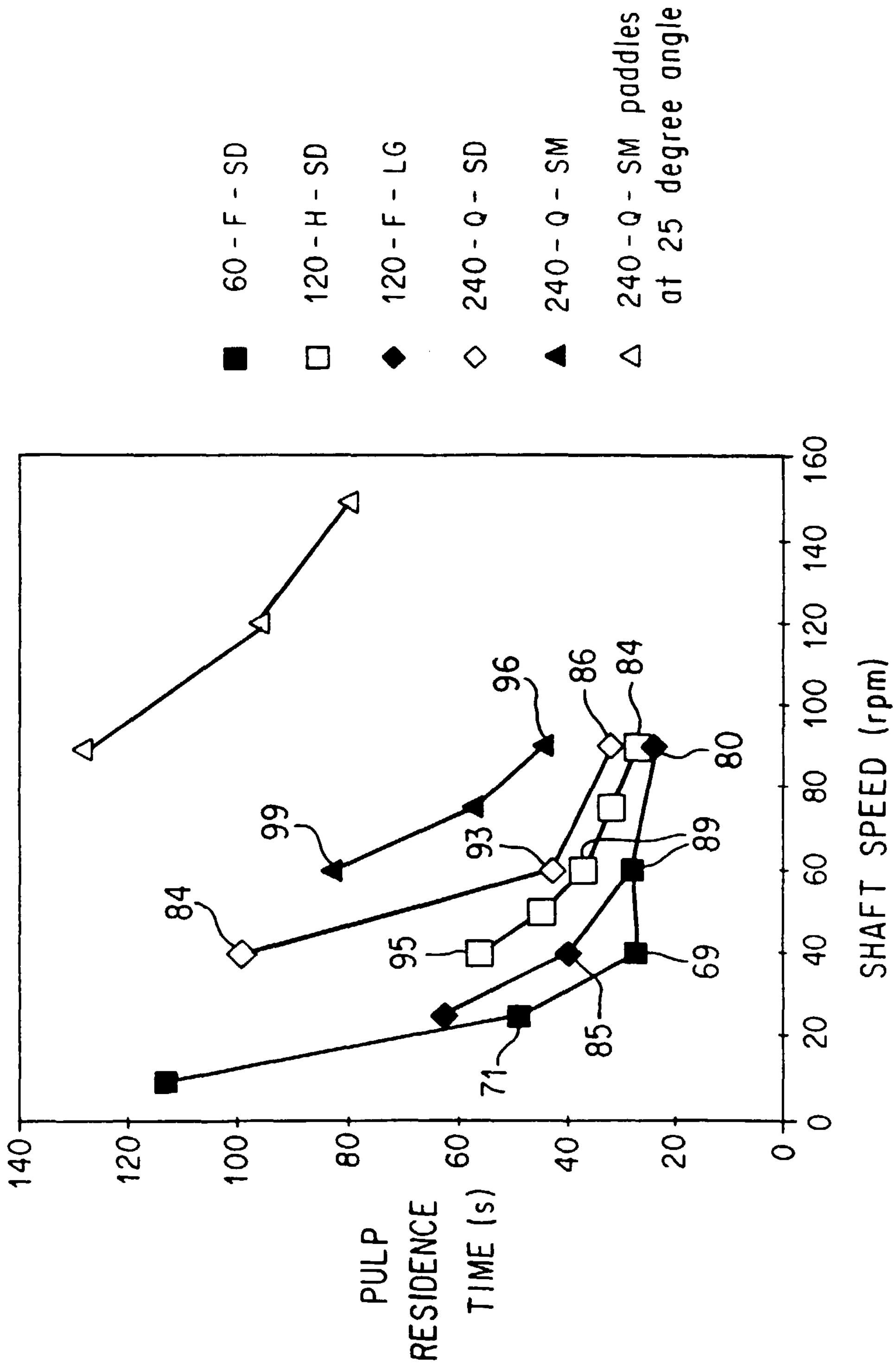
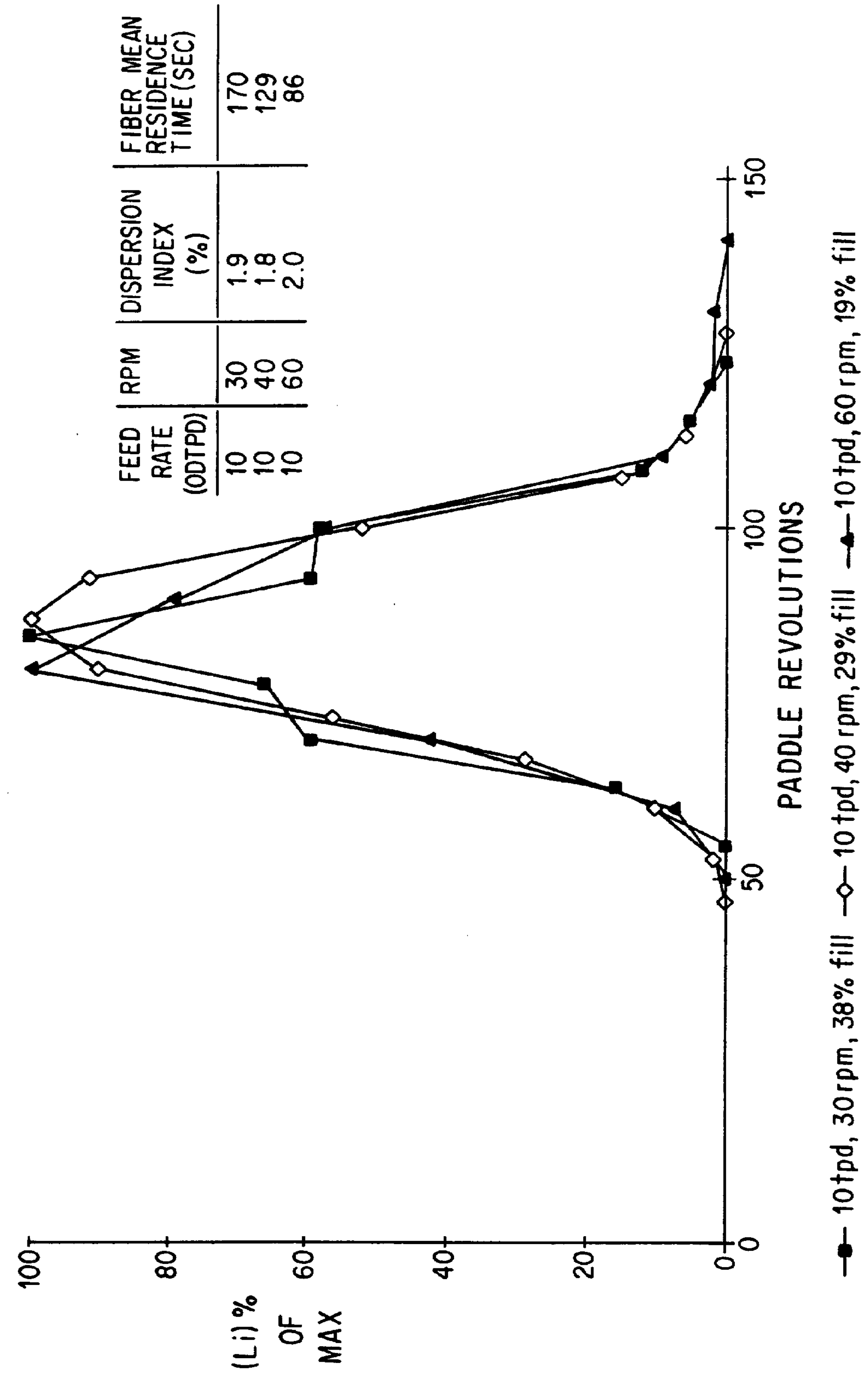

PULP RESIDENCE TIME (s)
SHAFT SPEED (rpm)
0
20
40
60
80
100
120
140
160
71
85
95
84
93
99
96
86
84
80
89
69
60 - F - SD
120 - H - SD
120 - F - LG
240 - Q - SD
240 - Q - SM
240 - Q - SM paddles at 25 degree angle

FIG. 21



FEED RATE (ODTPD)
RPM
DISPERSION INDEX (%)
FIBER MEAN RESIDENCE TIME (SEC)
10 30 1.9 170
10 40 1.8 129
10 60 2.0 86
(Li) % OF MAX
100
80
60
40
20
0
0
50
100
150
PADDLE REVOLUTIONS
10 tpd, 30 rpm, 38% fill
10 tpd, 40 rpm, 29% fill
10 tpd, 60 rpm, 19% fill

FIG. 22

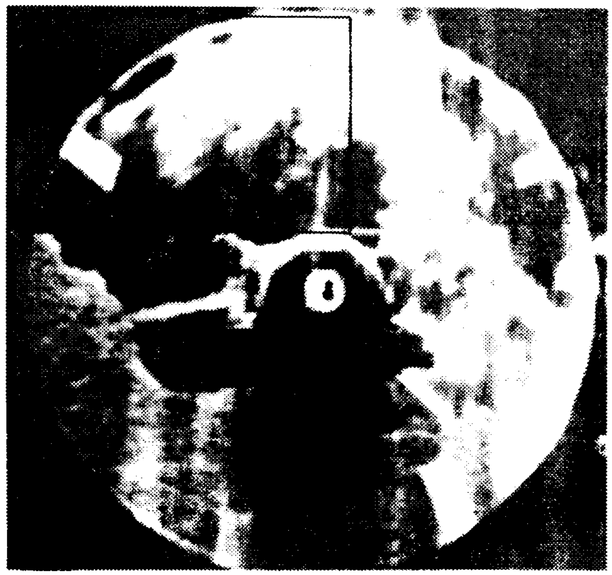
20 RPM shaft speed
22 % of boxed area contains pulp

FIG. 23

40 RPM shaft speed

47 % of boxed area contains pulp

FIG. 24



60 RPM shaft speed

58% of boxed area contains pulp

FIG. 25

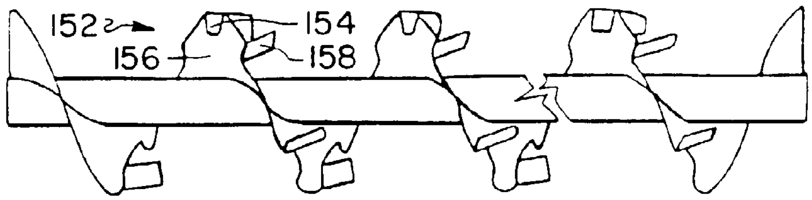


FIG.26

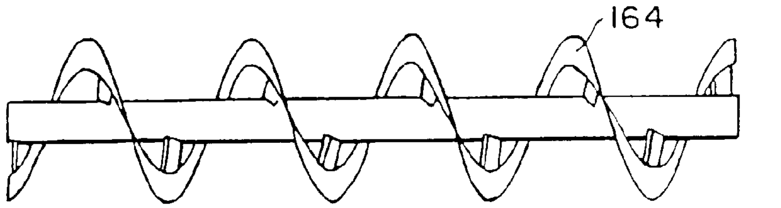


FIG.27

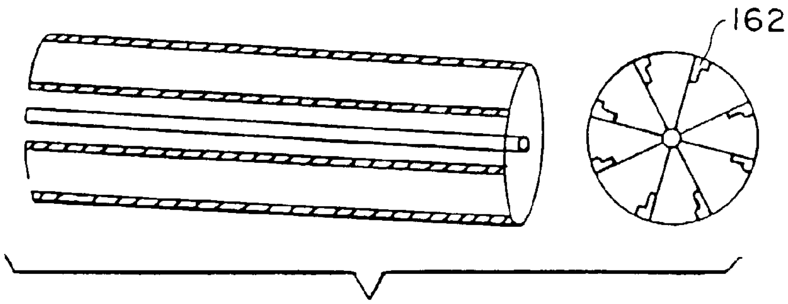


FIG.28

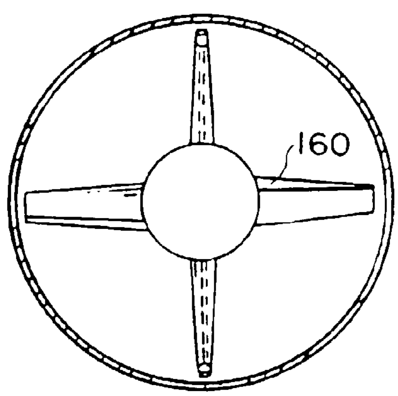


FIG.29